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Fissile Material Disposition Program

Deep Borehole Disposal Facility PEIS Data Input Report for Direct Disposal

Direct Disposal of Plutonium Metal/Plutonium Dioxide in Compound Metal Canisters

Version 3.0

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1.0	12/19/94	Borehole Facility Data Report	Ananda M. Wijesinghe & Ronald J. Shaffer	William G. Halsey	
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1. DEEP BOREHOLE DISPOSAL FACILITY—MISSIONS AND ASSUMPTIONS

1.1 Deep Borehole Disposal Facility Missions

Directives and Mission

Following President Clinton's Non-Proliferation Initiative, launched in September,1993, an Interagency Working Group (IWG) was established to conduct a comprehensive review of the options for the disposition of weapons-usable fissile materials from nuclear weapons dismantlement activities in the United States and the former Soviet Union. The IWG review process will consider technical, nonproliferation, environmental, budgetary, and economic considerations in the disposal of plutonium. The IWG is co-chaired by the White House Office of Science and Technology Policy and the National Security Council. The Department of Energy (DOE) is directly responsible for the management, storage, and disposition of all weapons-usable fissile material.

The Department of Energy has been directed to prepare a comprehensive review of long-term options for fissile material disposition, taking into account technical, nonproliferation, environmental, budgetary, and economic considerations. DOE's objectives in this task include the following:

- *Strengthening of national and international arms control efforts by providing an exemplary model for storage of all weapons-usable fissile materials and disposition of surplus weapons-usable fissile materials;*
- *Ensuring that storage and disposition of weapons-usable fissile materials is carried out in compliance with ES&H standards;*
- *Minimizing the prospect that surplus U.S. weapons-usable fissile materials could be reintroduced into arsenals from which they came and therefore increasing the prospect of reciprocal measures by Russia and other nuclear powers;*
- *Minimizing the risk that surplus U.S. weapons-usable fissile materials could be obtained by unauthorized parties; and*
- *Achieving these objectives in a timely and cost-effective manner.*

In response to the directive to the DOE, the Fissile Materials Disposition Program (FMDP) was created by the DOE to investigate the available alternatives. In a DOE-sponsored study by the Committee on International Security and Arms Control of the National Academy of Sciences entitled the "Management and Disposition of Excess Weapons Plutonium" in January 1994, the three most promising alternatives for long-term disposition of excess weapons plutonium satisfying these aims were identified as the following:

1. Fabrication and use of excess plutonium as fuel, without reprocessing, in existing or modified nuclear reactors;
2. Vitrification of excess plutonium in combination with high-level nuclear waste (HLW) and subsequent disposal in a high-level nuclear waste repository; and
3. Geologic disposal of the excess plutonium in deep boreholes.

Accordingly, the DOE has initiated a number of projects within the FMDP to investigate these and other alternatives. In particular, it created the Geologic Disposal Options (GDO) Task, having the charter to investigate all geologic options except emplacement in the Mined Geologic Disposal System, which is currently being developed for high-level waste (MGDS-HLW). It is the purpose of the GDO Task to develop a sufficient information base for these options to allow assessment of each option in a Programmatic Environmental Impact Statement and to permit comparison with the MGDS-HLW, for which a substantial base of data and evaluatory studies already exist.

Deep Borehole Disposition Alternatives

Driven by the recommendation of the NAS study and by a belief that the concept might offer advantages in effectiveness, cost, and speed for the Program mission, the initial focus of the GDO Task is on the Deep Borehole Disposition Option. The Deep Borehole Disposition Task will investigate in detail the feasibility of Direct and Immobilized Disposal of these fissile materials within deep boreholes drilled in appropriate stable geologic formations. The DOE has requested the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory to undertake this effort.

The preparation of a Programmatic Environmental Impact Statement is a requirement of the National Environmental Policy Act (NEPA). This report presents the data and supporting information necessary for the preparation of a PEIS for Direct Disposal of Plutonium in a Deep Borehole. The data consists of summaries of the facility design issues and concepts; descriptions of the facility structures, their layout, and the required support services; descriptions and quantities of the environmental emissions, effluents, and wastes generated by the facility; and its resource and employment needs. The data covers the construction, operation, closure, and post-closure performance phases of the facility. In addition to the conceptual design and the PEIS data for the facility, the report also addresses the Research, Development, Testing, and Risk Assessment activities that are required to support the engineering design and site selection for an actual facility.

The design presented in this report is a preliminary conceptual design for a new Deep Borehole Disposal Facility for Direct Disposal of Surplus Fissile Materials that, if built, would fully comply with applicable existing environmental, safety, and health laws, regulations, and orders. This design is only conceptual and is not intended to serve as a basis for setting up new engineering design and safety standards, which can be established only after significant additional work. The Deep Borehole Disposal Facility accepts surplus fissile materials (SFM) as plutonium metal and plutonium dioxide disposal form for permanent disposal in deep stable geologic formations. The disassembly and conversion of the original feed materials to plutonium metal and/or plutonium dioxide disposal form is assumed to be performed at a separate Disassembly & Conversion Facility located at a different site. A *Deep Borehole Disposal Facility PEIS Data Input Report for Immobilized Disposal* (Wijesinghe et al., 1996) similar to this report has been prepared for immobilized disposal of plutonium in a Deep Borehole Disposal Facility.

1.1.1 Overview of Deep Borehole Disposal Facility Design Concept

In the deep borehole concept for direct geologic disposal of surplus fissile materials, the material will be emplaced in the lower part of one or more deep boreholes drilled in tectonically, hydrologically, thermally, and geochemically stable rock formations (see Figure 1.1.1-1). Deep, Precambrian crystalline plutonic/metamorphic rock formations appear to have the most favorable characteristics for deep borehole disposal of fissile materials. The depths considered for the "emplacement zone" (2–4 km) in the deep boreholes are many thousands of meters greater than those of mined geologic repositories. The Pu/PuO_2 disposal form is emplaced in compound emplacement canisters as shown in Figure 1.1.1-2. The disposal form is packed and sealed in product cans, which are encapsulated in primary containment vessels (PCVs) approximately 0.14 m (5.5 in.) outer diameter and 0.51 m (20 in.) long. The PCVs are packed and sealed in emplacement canisters [0.41 m (16 in.) outer diameter, 6.1 m (20 ft) long]. The PCVs are arranged in three sets of three PCVs at each cross-sectional plane at a circumferential angular spacing of 120°, so that there are nine PCVs (containing a total of 40.5 kg of disposal form) per emplacement canister. Twenty-five emplacement canisters are screwed together to form a 152-m-long (500-ft) canister string, which is emplaced and grouted in place in the borehole as a single unit as shown in Figure 1.1.1-1. Thus one canister string contains a total of 1012.5 kg of disposal form. A total of full-length canister string and one partial length canister string containing 12.5 t of plutonium are emplaced in the emplacement zone of a single deep borehole. In this way, the full 50 t of plutonium available for disposal is disposed of in four deep boreholes. Once the emplacement zone of borehole is filled with emplaced material, the "isolation zone," which extends from the top of the emplacement zone to the ground surface, is filled and sealed with appropriate materials.

1.1.1.1 Proliferation Resistance

The high resistance to fissile material recovery offered by deep borehole emplacement in the present design arises from the great depth and the resulting difficulty of access (see National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, 1994). The deep borehole design therefore offers very high security against recovery by all except the host government in possession of the disposal site. Recovery by even the host government would be difficult, expensive, hazardous, time-consuming, and detectable. Thus, deep borehole disposal is essentially a method for permanent disposal of the disposed material without the intent of later retrieval.

1.1.1.2 Isolation of Radionuclides from the Biosphere

The deep borehole concept relies on the great distance from the biosphere and on the properties and integrity of the surrounding rock to isolate the emplaced fissile radionuclides from the biosphere over an indefinitely long performance period. Because plutonium has a very long half-life (24,400 yr) and because it decays to the even longer-lived fissile ^{235}U (710 million yr half-life), the length of this performance period is required to be much longer than the operational lifetimes of the order of 10,000 yr specified for nuclear waste repositories. The depth of the emplacement zone will be selected on the

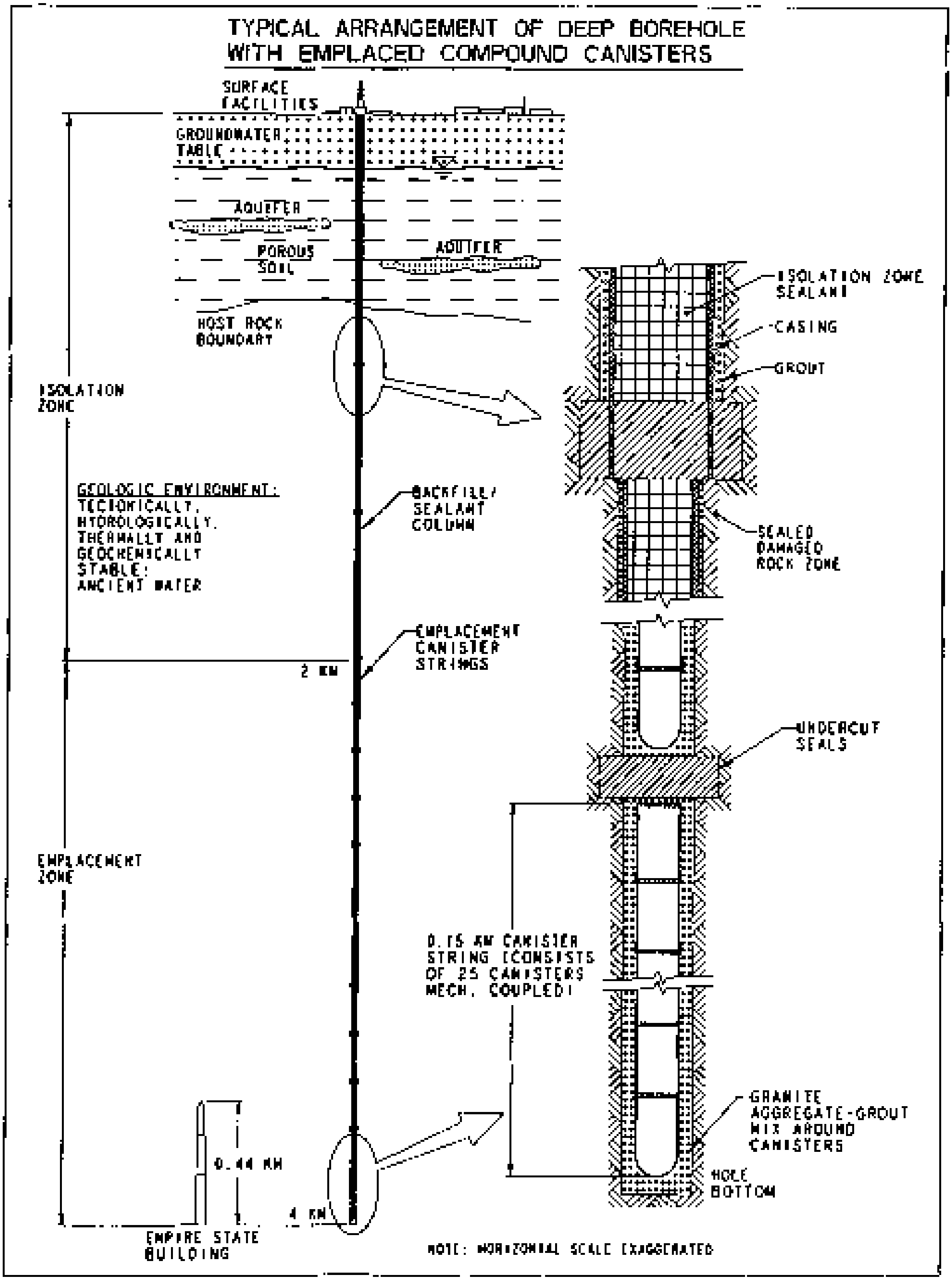

Figure 1.1.1-1. The Deep Borehole Disposal Concept for Direct Disposal of Plutonium Metal/Plutonium Dioxide in Compound Canisters.

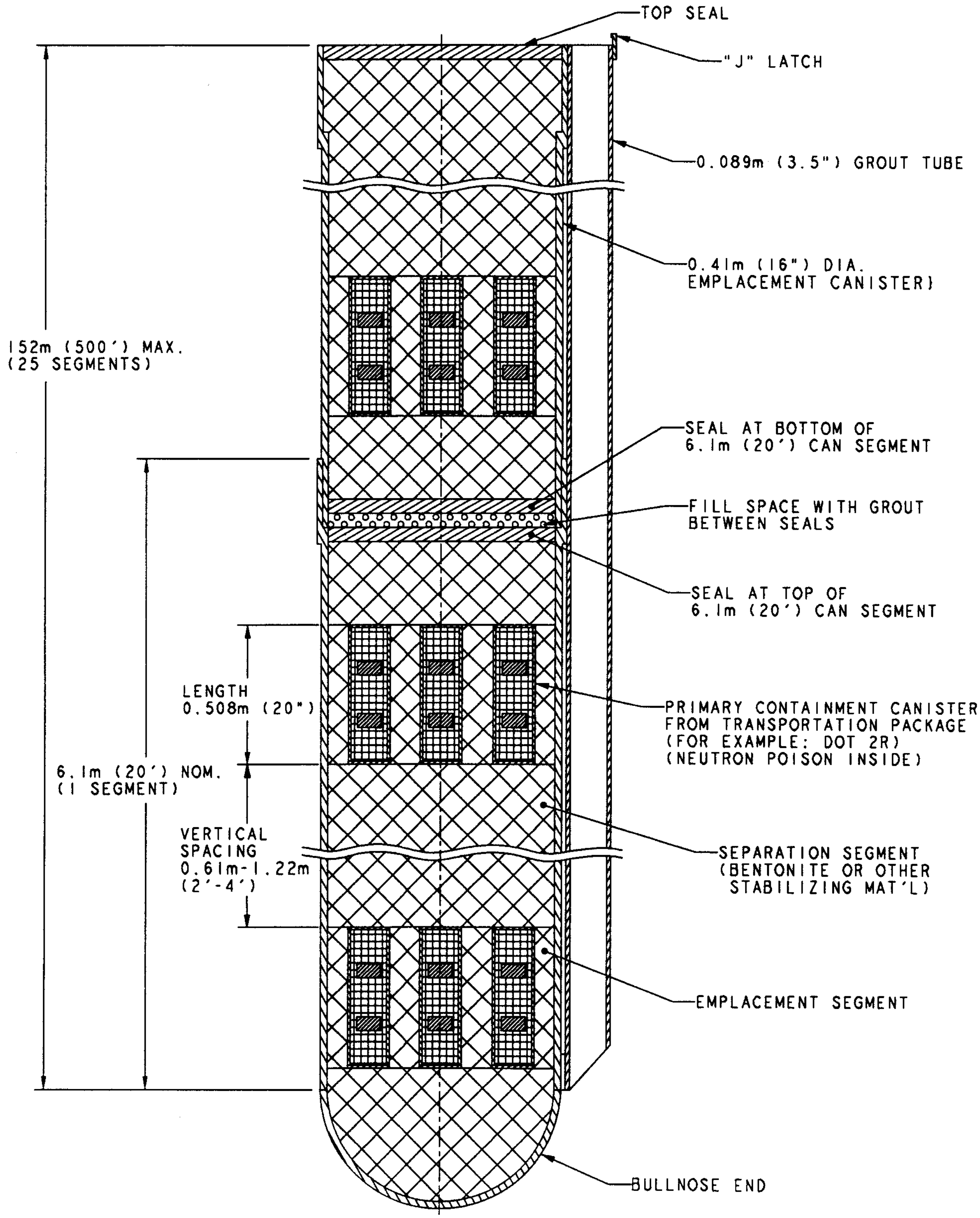

Figure 1.1.1-2. Design Configuration of the Compound Emplacement Canisters.

basis of performance analyses to ensure that the radionuclides emplaced in the borehole will never reach the biosphere or will have decayed to innocuous levels by the time they do reach the biosphere. The expectation that the deep borehole concept will be able to offer such performance is based on (1) the very slow movement of groundwater at great depths, (2) the slow release of radionuclides to the flowing groundwater by the disposal form, (3) the retardation of the movement of dissolved radionuclides by physico-chemical interactions with the rock, and (4) the capability to perform the drilling, emplacing, and borehole sealing operations without compromising the natural barriers of the geosphere or establishing new pathways for transport of the radionuclides to the biosphere.

Fissile Radionuclide Release Barrier

The fissile radionuclides may be emplaced in their original physical and chemical forms, or they may be first converted into an "immobilized" form that is more resistant to being dissolved by the brine at depth. Dissolution "releases" the material to the flowing brine, which transports it away from the borehole, through the geosphere and possibly towards the biosphere. The rate of release of fissile materials to the flowing brine is proportional to the product of the intrinsic dissolution rate of the disposal form per unit exposed surface area and the total surface area exposed to the flowing brine. The brines, however, are believed to be essentially dormant at great depths at appropriately selected sites. Transport of the plutonium released by dissolution through the geosphere would occur by both advective transport by the flowing brine and molecular diffusion in the brine and rock. If the brine flow velocity is negligible as a result of appropriate site selection, the transport would occur at an extremely slow rate by molecular diffusion only. Therefore, another key design objective would be to minimize the flow of brine through the deep borehole, first by selecting a site with as few natural flow pathways and flow initiating forces as possible, and second by inserting engineered barriers to fluid flow between the disposal form and its surroundings.

Engineered Hydraulic Barriers

Engineered flow barriers can take many forms. First, canisters can be used to contain and confine the disposal form, and second, hydraulic seals can be installed within the borehole surrounding the canistered disposal form to prevent the passage of brine. However, given the corrosive nature of the brines and the high temperatures and stresses at depth, it is unlikely that any canister would survive more than a few hundred years. Therefore, canisters contribute to the safety of the surface processing and emplacement operations but do not significantly contribute to the long-term post-closure performance of the deep borehole disposal method. The impact of corroded canister materials on the sealing of the emplacement zone against the flow of brine and the transport of fissile materials is uncertain and requires further investigation. Second, specially formulated sealing plugs, made from durable and nearly natural sealing materials, will be installed across the entire borehole cross section at strategic locations within the borehole. In addition, natural fractures and the drilling-induced near-field damage zone in the adjacent rock will be sealed to reduce the influx of brine.

Engineered Transport Barriers

Engineered hydraulic barriers at depth are unlikely to be perfect seals and may degrade with time. Since preventing the escape of contaminants from the borehole, rather than preventing the transit of water through the borehole, is the ultimate objective of barrier design, imperfections in the design of hydraulic barriers can be offset by exploiting the capability of certain materials to sorb dissolved contaminants in the same way that contaminants are sorbed by the host rock. This presents an opportunity to embed a supplementary "chemo-sorptive transport barrier" functionality in engineered hydraulic seals. Finally, through the proper choice of borehole sealants, and by introducing appropriate chemical additives, it is possible to alter the aqueous chemistry of the brine within the borehole to reduce the dissolution rate of the disposal form.

Unlike radioactive fission products in high-level waste and in spent fuel, plutonium does not generate a significant amount of heat (less than 3 W/kg for Pu) due to radioactive decay. As a result, heat generation by the plutonium is not great enough to disturb the stagnant fluid regime at depth. However, sealing material degradation, enhanced dissolution of the disposal form by oxidants produced by water radiolysis, and gas generation due to degradation of materials must be considered. For example, plutonium emits alpha radiation, which is known to cause transformation of bentonitic sealing materials to amorphous silicious masses. These factors are particularly important to the durability of engineered barriers.

The Natural Transport Barriers

Irrespective of whether the contaminant is transported by advection with the flowing brine and/or by molecular diffusion, the contaminant will interact physico-chemically with the surrounding rock with the result that a portion of it will be "sorbed" onto the rock surface. Sorption of the contaminant by the rock reduces the effective speed with which the contaminant moves through and disperses within the rock by advection and molecular diffusion. The greater the sorption by the rock, the slower is the movement of the contaminant away from the source. Consequently, the geosphere itself serves as a "natural transport barrier" that helps to retard the escape of the contaminants from the borehole and their subsequent movement towards the biosphere. Plutonium, in particular, is highly sorbed, and its movement retarded, by most rock types; the unretarded transport time is increased by a factor of 50–10,000. For example, neglecting the dissolution-rate limitation on plutonium mobilization, if the brine at an average depth of 3 km flows towards the surface at a uniform velocity of 1 cm/yr, and if the retardation factor is uniform and is equal to 1000, the travel time to the surface for plutonium dissolved in brine at that depth would increase from 300,000 yr to 300 million yr.

At great depths in tectonically, thermally, hydraulically, and geochemically stable rock formations, the brine flow velocities are expected to be very small. This is advantageous because it reduces the corrosion and degradation of emplacement canisters and borehole seals, the rate of release of fissile materials to groundwater through dissolution, and the rate of convective transport of dissolved contaminants through the surrounding geosphere towards the biosphere. Usually, candidate host-rock types are expected to have few fractures at depth, and the apertures and hydraulic conductivities of the fractures that do exist are expected to be much smaller than at shallow depths. However, this is an area of controversy, because although the porosity and permeability of intact plutonic/metamorphic rocks are expected to be very small at great depths because of flow and healing under large compressive in situ stresses, there is also evidence that great depth does not guarantee that the fractures and faults will be closed.

More importantly, in normally pressurized host-rock media at great depths, there is likely to be negligible net driving pressure to cause fluid flow, as indicated by the presence of ancient connate waters in granitic rocks at great depths. One force that potentially could initiate fluid circulation at depth is the buoyancy pressure force caused by the increase of temperature with depth. However, effective fluid density is a function not only of temperature but also of the concentration of salt in solution. In normally pressurized areas with normal geothermal gradients (15–25°C/km), it can be shown that the presence of moderate salinity gradients (e.g., 2% per km) would prevent hydrothermohaline instabilities from developing into fluid circulation loops for even relatively large fracture permeabilities. The stability of this stagnant fluid regime can be disturbed in a number of ways, however. These include, for example, the introduction of large heat sources [e.g., heat of radioactive decay from high-level waste (HLW) or criticality-induced heating and steam generation], formation of pressurized fluid zones by earthquake-generated rock mass displacements, and the linking-up of highly permeable existing fault zones by further faulting. Therefore, to exploit the absence of fluid flow and convective transport, criteria for the selection of a site for a deep borehole disposal facility must include the following: (1) seismic stability, (2) low geothermal gradient, (3) high salinity gradient, (4) low density of fracturing, (5) the absence of nearby active fault zones, and (6) the presence of very old, undisturbed connate water.

1.1.1.3 Pre-Closure Safety

The environmental, safety, and health impacts of the transporting, processing, emplacing, borehole sealing, decontaminating, and decommissioning activities that precede the closure of the deep borehole disposal facility are important issues that affect the decision to choose a disposition alternative. However, compared with the difficulties and uncertainties involved in ensuring post-closure safety over an indefinitely long performance period, pre-closure risks are controllable aspects of the deep borehole disposal facility design that can be reduced to acceptable levels by adopting appropriate facility design safety margins and administrative procedures. Accordingly, pre-closure safety is an important but secondary issue in deep borehole facility design.

The design of the deep borehole disposal facility will include the basic controls for assuring nuclear criticality safety in the Surface Processing Facility and the Emplacing–Borehole Sealing Facility, during on-site transportation of the disposal form feed material between the site perimeter and the Surface Processing Facility, and during transportation of processed disposal form from the Surface Processing Facility to the Emplacing–Borehole Sealing Facility. The process designs will satisfy the double-contingency principle; that is, "process designs shall incorporate sufficient safety factors so that at least two unlikely, independent, and concurrent changes in process conditions must occur before a criticality accident is possible." Basic control methods for the prevention of nuclear criticality include (1) provision of safe geometry (preferred), (2) engineered density and/or mass limitation, (3) provision of fixed neutron absorbers, (4) provision of soluble neutron absorbers, and (5) use of administrative controls.

Although geometric controls are used extensively wherever practical, there are cases where geometric control alone cannot practically provide assurance of criticality safety. In these cases, engineered controls can be used to control neutron moderation, neutron absorbing poisons, and the mass and concentration/density of the materials.

Criticality Safety of Initial Emplacement Configuration and Emplacement Accidents

In the direct disposal option, the initial criticality of the plutonium in the emplacement configuration at emplacement time can be controlled by appropriate choice of the mass of plutonium in each product can; the design dimensions, spacing, and arrangement of the product cans within the emplacement canister; the spacing between the emplacement canisters; and the composition-dependent nuclear properties of the materials used in the design. The criticality analyses used for designing the emplacement configuration must account for the presence of the fissile material and for the nuclear moderation, reflection, and absorption properties of the adjoining materials. The materials that must be considered in the analyses include the sealant materials within the emplacement canister, the canister material, the sealants/concretes between the canister and the borehole wall, and some portion of the host rock itself. In particular, it is necessary to consider the moderating effects of hydrogen in the bound water in the concrete/grouts and in the brine invading the interstitial pore space of all materials external to the emplacement canister.

A considerable effort has been devoted in the present design to ensuring criticality safety of the initial emplacement configuration. Some effort has been expended on analyzing the criticality safety of accidents during the emplacement process. These analyses, which are briefly outlined in Section 2.2.6.3, indicate that the design has a large margin of safety in the initial emplacement configuration.

1.1.1.4 Post-Closure Criticality Safety

Depending on the circumstances, criticality of the plutonium disposed in the subsurface may become an issue after a long time. In contrast to nuclear waste disposal, criticality (rather than the heat generation rate) will be the primary determinant of the plutonium loading in the emplaced disposal form. Among the issues that must be addressed are: (1) the impact on criticality safety of moderation by the hydrogen in brine that will permeate the borehole and the disposal form, (2) criticality due to dissolution, transport, and precipitation/sorption scenarios, (3) criticality in earthquake-disrupted emplacement geometries, (4) the consequences of post-closure criticality on borehole sealing, (5) fluid circulation in the geosphere due to criticality-induced heat generation, (6) production and possible transport of fission product contaminants to the biosphere, and (7) the venting of the borehole due to complete failure of containment during a criticality event. It is also necessary to investigate (8) the addition of neutron-absorbing poisons (e.g., gadolinium, hafnium, europium, samarium, boron) to the sealants/filler materials surrounding the non-immobilized disposal form as insurance against criticality and as a means of increasing plutonium loading in the disposal form without inducing criticality. If neutron poisons are added to these sealant/filler materials for these purposes, another issue that must be assessed is (9) the effect of separation of the neutron poison from the plutonium it is designed to control during disposal form and sealant/filler material dissolution, neutron poison release, and sorptive transport.

Long-Term Criticality Safety of Undisrupted Configurations

In addition to the considerations addressed in Section 1.1.1.3 regarding criticality safety at the time of initial emplacement, additional short-term, intermediate-term, and long-term scenarios will have to be considered to evaluate criticality safety under normal operating and natural event–induced accident conditions. Long-term criticality evaluations are necessary because both ^{239}Pu and its alpha-decay product ^{235}U are fissile and very long lived (half lives 24,400 and 7.1×10^8 yr, respectively). In particular, it is necessary to consider short-term scenarios in which the emplacement configuration remains unaltered but the flow barriers to brine influx from the surrounding geosphere have failed. Owing to any of a number of possible mechanisms such as corrosion, stress-corrosion cracking, and disruption by earthquakes, even the most corrosion-resistant canisters are likely to fail after a relatively short period of, say, 200 yr. This is particularly true because of the high temperature (120–150°C) and high salinity (as much as 30%) of the brines within a deep borehole. Consequently, the entire borehole, including the canister, the interstitial pore space of the concrete, the sealants, and the plutonium disposal form, will become saturated with brine from the external environment. The plutonium disposal form and the spacing and geometric configuration of emplacement must be designed to be safe under such a scenario.

Some effort has been devoted in the present design to ensuring long-term criticality safety of undisrupted emplacement configurations. These analyses, which are briefly outlined in Section 2.2.6.3, will be extended as part of the research and development program.

Long-Term Criticality Safety of Disrupted Configurations

Furthermore, it is necessary to consider additional long-term scenarios in which the geometric configuration at emplacement is completely disrupted, the plutonium in the disposal form is redistributed by physical rearrangement or by leaching out by brine, and additional dissolved plutonium from another location in the borehole invades and displaces the non-plutonium-bearing brine within the pore space.

A moderate amount of effort has been devoted in the present design to ensuring criticality safety of disrupted emplacement configurations. These results, which are briefly outlined in Section 2.2.6.3, will be extended as part of the research and development program.

Long-Term Criticality Safety of Geochemical Reconcentration Scenarios

In addition to the foregoing scenarios, it is necessary to evaluate the long-term risk of criticality, within the borehole or within an undetected closely spaced set of fractures in the surrounding host rock, due to *slow but continuous* leaching of plutonium from the disposal form by recirculating brine, transport into other regions, and reconcentration at one location through continuous precipitation or sorption under different conditions of temperature and brine chemistry. The existence of sufficiently high brine flow velocities, originating from thermohaline convective instability of brine in fractures or from some other mechanism, would be necessary for such reconcentration scenarios to be of concern. However, preliminary estimates show that even moderate salinity gradients have a strongly stabilizing effect and prevent the initiation of brine circulation.

No quantitative analyses of criticality safety of the long-term geochemical reconcentration scenarios have been performed, because of resource and time limitations. Because of the complexity of the coupled phenomena and the significant effort that would be required, these analyses will be undertaken as part of the research and development program in the first five years of the deep borehole disposition program.

1.1.1.5 Timeliness of Implementation

The primary impediment to speedy implementation of the deep borehole disposal method is the length of time required for the research, development, testing, site characterization and licensing activities (an estimated 5–10 yr), and the subsequent licensing and permitting. Once these activities are completed, it appears that the deep borehole disposal facility can be rapidly built at a relatively low cost compared with other final disposition options.

1.1.1.6 Cost of Implementation

The cost of the research, development, site characterization and licensing activities can be a significant component of the overall cost. Immobilization costs are avoided with direct disposal, but high canister, borehole emplacement zone sealing, and canister emplacement costs are incurred.

1.1.2 Long-Term Performance Strategy of the Design Concept

The long-term performance strategy of the direct disposal option is as follows:

The site will be carefully selected to provide a tectonically, hydrologically, thermally, and geochemically stable host rock formation without fluid circulation at depth and having strong evidence that the fluid has remained stagnant at depth for a geologically long time. A site satisfying this criterion is likely to have the following characteristics: (1) seismic stability, (2) low geothermal gradient, (3) high salinity gradient, (4) low density of fracturing, (5) the absence of active nearby fault zones, and (6) the presence of very old, undisturbed connate water.

Compound metallic canisters will be used for isolation, and appropriate sealing materials will be used to retard radionuclide migration and dissolution.

In summary, for long-term performance, the design relies on the following:

1. The natural system barrier and the durability of the long seal in the isolation zone and the emplacement zone seals to ensure isolation of the emplaced radionuclides from the biosphere over an indefinitely long performance period.

2. Spatial separation of small, concentrated plutonium masses to subcritical loadings as the first line of defense against criticality, and optional neutron absorbers in the canister sealants as a supplementary second line of defense against criticality.

3. The great depth of disposal as the barrier against proliferation.

1.2 Deep Borehole Disposal Facility Assumptions

1.2.1 Deep Borehole Disposal Facility Capacity/Capability

The deep borehole disposal facility is assumed to be generic in both design and geographic location. The plutonium is disposed of as plutonium metal or plutonium dioxide encased in compound metal canisters. The design depends on the physical inaccessibility of the material at depth for security. The design assumes that 50 t of plutonium, will be disposed of at the facility over a 10-yr period at a rate of 5 t/yr. The surge capacity (i.e., the maximum possible processing rate of the facility), will be 10 t/yr. Although this is the currently assumed disposal campaign for sizing the Deep Borehole Disposal Facility, different feed rates and disposal periods can be easily accommodated by appropriately resizing the facility within the scope of the existing design concept. Such operational scenarios are presented in the *Alternative Technical Summary Report for Direct Disposal of Plutonium Metal/Plutonium Dioxide in Compound Canisters* (Wijesinghe et al., January 15, 1996).

1.2.2 Facility Operating Basis

The Surface Processing and Emplacing–Borehole Sealing Process Facilities of the Deep Borehole Disposal Facility will operate 7 days/week, 24 hr/day, in two 12-hr shifts with three drilling crews. The surge rate will be handled by introducing a second 8-hr shift in the Surface Processing and Emplacing–Borehole Sealing Facilities and by adding a second drilling rig and extra crews, if needed, in the Drilling Facility.

The schedule for the Direct Deep Borehole Disposal Alternative in Figure 1.2.2-1 shows the schedules for the Licensing & Permitting, Research & Development, Design & Construction, Operation, Closure (D&D), and Post-Closure Monitoring activities. The estimated start date is September 1, 1996. Further discussion of individual activities is presented in the following subsections.

1.2.2.1 R&D Effort

A comprehensive five-year R&D effort has been planned to support the facility design, site characterization and site selection, licensing, emplacement, and closure phases of the Deep Borehole Disposal option for the disposition of the disposal form. The areas requiring research and development are as follows:

1. Site characterization, including vertical and horizontal flow rates of brine; geochemical composition, pH, and Eh of brines at depth; temperature and salinity gradients; compositional, chemical, hydrological, thermal, and mechanical properties of host rock at depth; characterization of fracture distribution and properties; borehole logging, surface seismic and cross-borehole acoustic/electrical tomographic imaging for definition of geologic structure and rock properties; cross-borehole pressure and tracer tests for hydrologic characterization; tectonic and seismic stability of the geologic formation.

2. Field technologies, including drilling methods; borehole accuracy, deformation, and stability; sealing technologies for undercut emplacement-zone seals, isolation zone sealing, and sealing fractures; and quality assurance for subsurface operations.

3. Downhole materials performance, including disposal form dissolution and leaching at deep borehole conditions; solubility of plutonium in brine at depth; transport properties of plutonium in host rock and the pathway to biosphere; durability, selection, and performance of grouting/sealing materials; effects of radiolysis on downhole materials; and criticality-related properties of disposal forms, grouts, brines, and host rock.

4. Post-closure phase performance assessments, including mechanisms for initiation of fluid flow; transport of plutonium and daughter products in borehole and host rock and along pathways towards the biosphere; plutonium release rate from the disposal form; plutonium reconcentration mechanisms and evaluation of long-term criticality risk; borehole integrity; grout durability and performance; ES&H, criticality, and proliferation risk assessments; natural analog studies of naturally occurring geologic reactors to support long-term performance predictions; integrated systems-level performance; and cost analyses for design optimization.

These R&D needs would be addressed in a five-year plan geared to the following:

1. *Acquiring the required field data* on the conditions at large subsurface depths through an experimental site characterization program at a typical site.

2. *Extending and specializing existing performance analysis models or developing new models* for coupled fluid flow, reactive fissile material transport, disposal form dissolution and fissile material release, downhole short- and long-term criticality assessments, geomechanical analyses, ES&H and proliferation risk assessments, and cost analysis to the deep borehole application.

3. *Acquiring unavailable data* required by the above predictive models through laboratory and field experiments that simulate downhole conditions.

4. *Developing the required engineering and operations technologies* required to safely and efficiently implement the site characterization, drilling, emplacing, borehole sealing, and remote monitoring activities

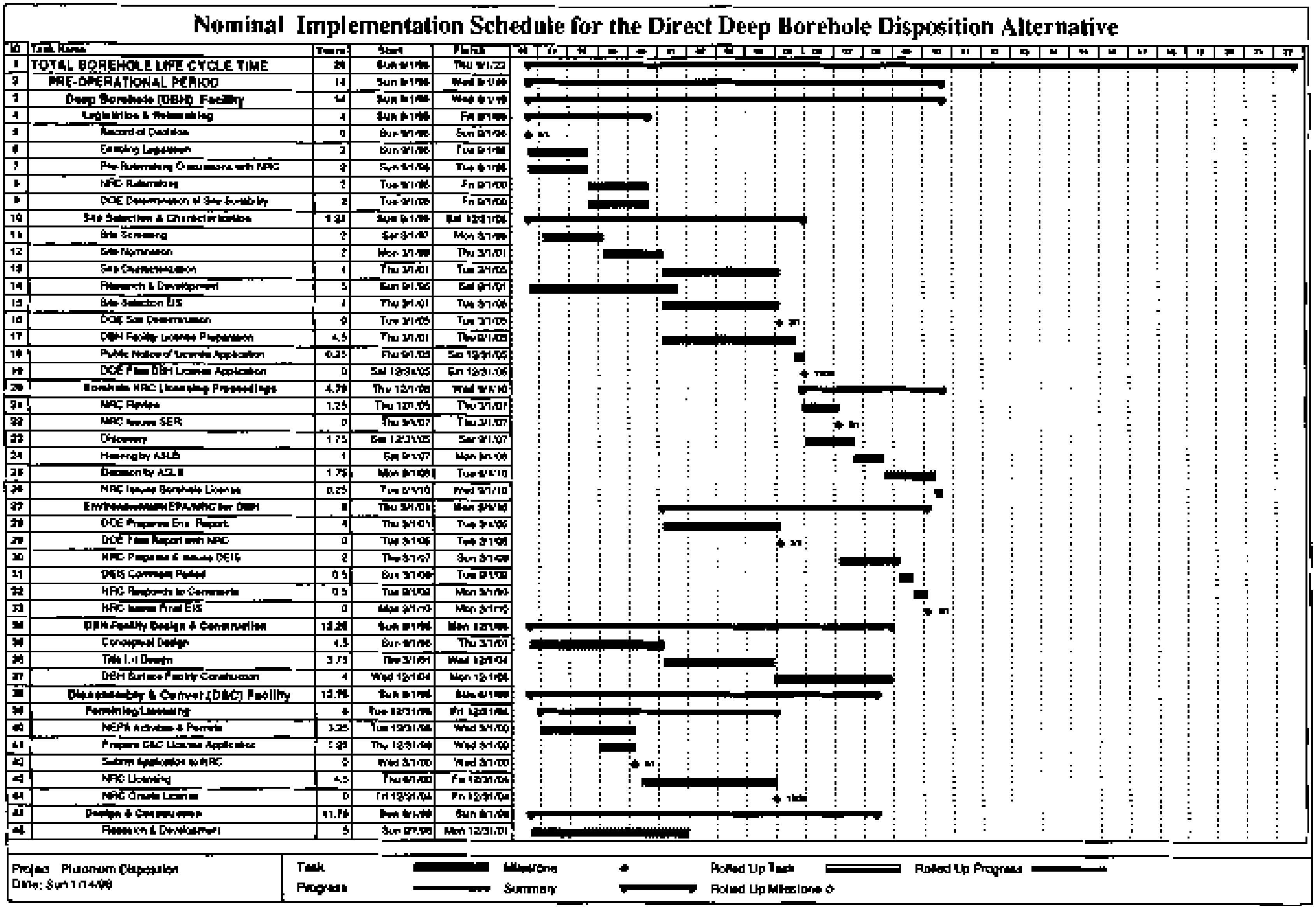

Figure 1.2.2-1. Deep Borehole Disposal Facility Overall Project Schedule.

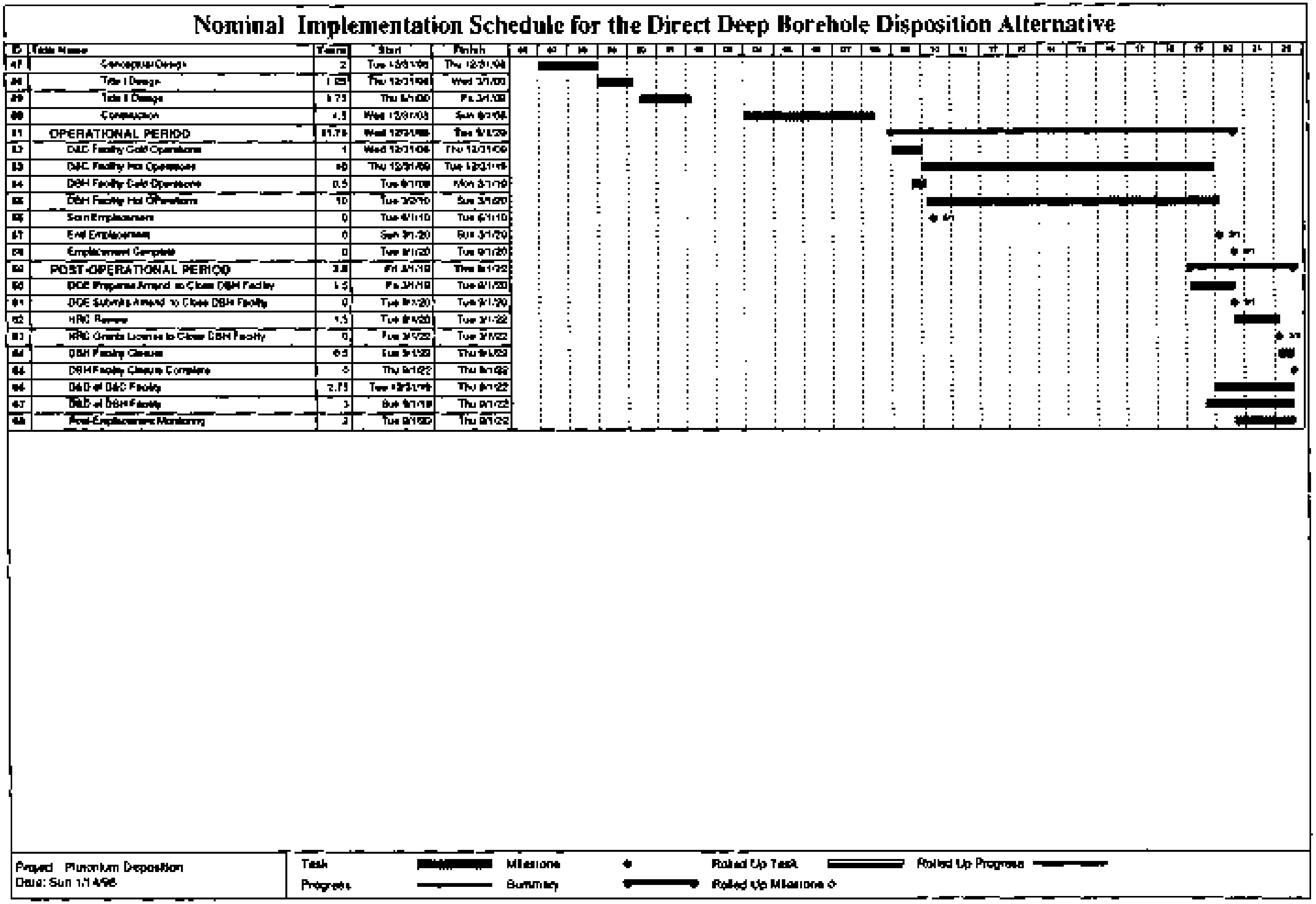

Figure 1.2.2-1. Deep Borehole Disposal Facility Overall Project Schedule (Continued).

associated with construction, operation, and post-closure performance of a Deep Borehole Disposal Facility.

5. *Performing the long-term performance, risk, and cost assessments* required to support the facility design and licensing activities.

6. *Demonstrating the developed drilling, emplacement, and sealing technologies* through a pilot large-diameter deep borehole field demonstration.

This R&D program would begin at the start of the deep borehole disposition program in September 1996 and would continue for five years until September 2001, as shown in the Implementation Schedule in Figure 1.2.2-1.

1.2.2.2 Permitting and Licensing Schedule

The establishment of a regulatory basis for the disposal of excess special nuclear material is necessary prior to obtaining permits and licenses for the deep borehole project. The regulatory basis may require 4 yr to synthesize the regulations, give public notice, and conduct all the public hearings that are part of the process. It is expected to begin at the start of the deep borehole disposition program in September 1996 and to continue until September 2000.

From the time that the regulations are established, the permitting and licensing schedule will require an additional 5 yr to certify the site. This includes producing the site-specific Environmental Impact Statement (EIS), holding public hearings, and certifying that the site will meet the design and performance criteria necessary to meet the regulations and satisfy the mitigations given in the EIS. The Site Selection and Characterization in support of this activity will begin in September 1996 at the beginning of the deep borehole disposition program and will culminate with DOE's filing of the deep borehole disposal facility license application in December 2005. This will be followed by the license review and approval process that includes review by the Nuclear Regulatory Commission (NRC), public hearings, and decision making by the Atomic Safety Licensing Board (ASLB) culminating in the NRC issuing a license to construct and operate the facility in June 2010.

1.2.2.3 Construction, Operation, Closure, and Post-Closure Schedules

The Implementation Schedule to deploy, operate, and decommission the deep borehole disposal facility is given in Figure 1.2.2-1. As indicated in the schedule, conceptual design of the Deep Borehole Disposal Facility begins immediately at the beginning of the deep borehole disposition program in September 1996 and continues until April 2001. The conceptual design is required for the preparation of the EIS by the DOE. Title I design begins at the same time as the preparation of the site-specific EIS. Title I & Title II (preliminary and detailed design) is estimated to require approximately 3.75 years to complete. This will allow construction to start in December 2004. Construction is estimated to require about 4 years, leading to start of operations of the facility in September 2009.

After initial preparation and drilling, emplacement operations are assumed to start in April 2010, to continue for 10 yr, and to be complete by April 2020. Decontamination and decommissioning of the facility is estimated to require approximately 3 yr, resulting in an overall program completion date of September 2022.

The emplacement operations for this option could be accelerated and completed in 3 yr if the plutonium final form material could all be shipped to the borehole site within that period. This will accelerate the overall program completion date to December 2015.

1.2.3 Compliance

1.2.3.1 Rules, Regulations, Codes, and Guidelines

The regulations that cover the requirements that must be met for the disposal of plutonium in a deep borehole disposal facility address a wide variety of issues, including transportation, operation of the Surface Processing Facility, emplacement and sealing of the boreholes, closure of the facility, post-closure performance, and possibly post-closure monitoring.

Existing regulations that could apply to the development of regulations for a deep borehole disposal facility are summarized in Figure 1.2.3.1-1. The off-site transportation of excess nuclear material will be covered by 49 CFR 173.7 for U.S. Government material, with 49 CFR 173 Subpart I for radioactive materials. The packaging will be certified to be in conformance with 10 CFR 71. The transportation of the material will conform to IAEA Safety Series No. 6 and to the additional requirements for the shipment of plutonium given in 10 CFR 71. Safeguards and Security for off-site shipments must conform to 10 CFR 73.26.

On-site activities must conform to the procedure rules given in 10 CFR 820. Nuclear safety management at the site will conform to the use in the proposed 10 CFR 830 regulation. Occupational radiation protection will conform to 10 CFR 835. The quality assurance program will be similar to 10 CFR 60 Subpart G, which will form the basis for the QA program for the facility.

1.2.3.2 Safeguards and Security

Safeguards and security protection for the disposition of excess special nuclear material are assumed to conform to the applicable sections of DOE 5630 series orders or their appropriate future alternatives.

1.2.3.3 Environmental, Safety, and Health (ES&H)

The various areas of ES&H that are of significant concern for the deep borehole disposal facility include the contamination of water by the processing of the excess plutonium and exceeding the allowable concentration of plutonium in the air at the site. The national primary drinking water regulations and implementation given in 40 CFR 141 and 40 CFR 142 will be adhered to. The standards for protection against radiation are given in 10 CFR 20 for the concentration of plutonium in air and water. In addition, the processing of plutonium may produce wastes that will require disposal. The introduction of any hazardous wastes into the waste stream or the feed stream must be minimized. Hazardous wastes are listed in 40 CFR 261.31 through 40 CFR 261.33. Any other waste must be characterized by tests described in 40 CFR 261.20 through 40 CFR 261.24 to determine if it is hazardous.

1.2.3.4 Buffer Zones

For the purpose of preparing this document, no site-specific data can be given for an actual site because no specific site has been selected. Instead, the data provided is for a generic example site. A site map for the Deep Borehole Disposal Facility, showing a buffer zone, is presented in Figure 3.1.7-1. The overall site with a four-hole Borehole Array at 500 m (1,640 ft) hole spacing occupies a land area of approximately 2,041 hectares (5,044 acres), of which 32 hectares (78 acres) is occupied by the Main Facility, 25 hectares (62 acres) by the Borehole Array, and 1,873 hectares (4,628 acres) by the Buffer Zone. The site dimensions are as follows: entire site 4,447 m × 4,590 m (14,590 ft × 15,060 ft), Main Facility 229 m × 1,067 m (750 ft × 3,500 ft), and Borehole Array 500 m × 500 m (1,640 ft × 1,640 ft). This drawing depicts a representative arrangement of facility buildings and site-support areas anticipated for the Deep Borehole Disposal Facility for direct disposition.

1.2.3.5 Decontamination and Decommissioning

At the time of closure, the facility will contain residuals of plutonium and other waste produced during the processing of the plutonium at the site. The waste may include TRU waste to be disposed of in the WIPP facility. For concentration of plutonium less than 100 nCi per gram, the TRU waste may be eligible for land disposal in conformance with 10 CFR 61. Radioactive waste management must conform to DOE Order 5820.2A.

1.2.3.6 Non–Safety/Safety Class

A graded approach may be used to identify components that are important to safety. Components that have a major impact on safety will have different design criteria than components having only a minor impact on safety. This approach is used in the nuclear power industry, where the section of the ASME code used in the design depends on the function (and the importance to safety) of the component. The design of structures, systems, and components important to safety shall conform to mission-specific regulations (to be developed) similar to 10 CFR 60.131(b).

1.2.3.7 Toxicological/Radiological Exposure

The toxicological/radiation exposure during construction will be controlled by the EPA and OSHA. The Safe Drinking Water Act and the Clean Air Act will regulate the quality of water and air at the site during construction and operation.

The technical criteria for the allowable radionuclide activity in air and water are given in 10 CFR 20. The environmental standards for the groundwater are given in 40 CFR 191 Subpart A. The long-term individual protection requirements are given in 40 CFR 191.15. NESHAP (40 CFR Part 61, Section 112) dose exposure limits to a member of the general public are 10 mrem/yr from facility operations. The average dose to the population from natural background sources is 300 mrem/yr.

The operation area shall be designed so that radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 until permanent closure has been completed.

Surfaces facility ventilation and radiation control and monitoring should be consistent with 10 CFR 60.132 (b) and (c).

1.2.3.8 *Waste Management*

Radioactive waste treatment facilities shall be designed to process any radioactive wastes generated at the facility operations area into a form suitable to permit safe disposal at the site or to permit safe transportation and conversion to a form suitable for disposal at an alternative site in accordance with applicable regulations.

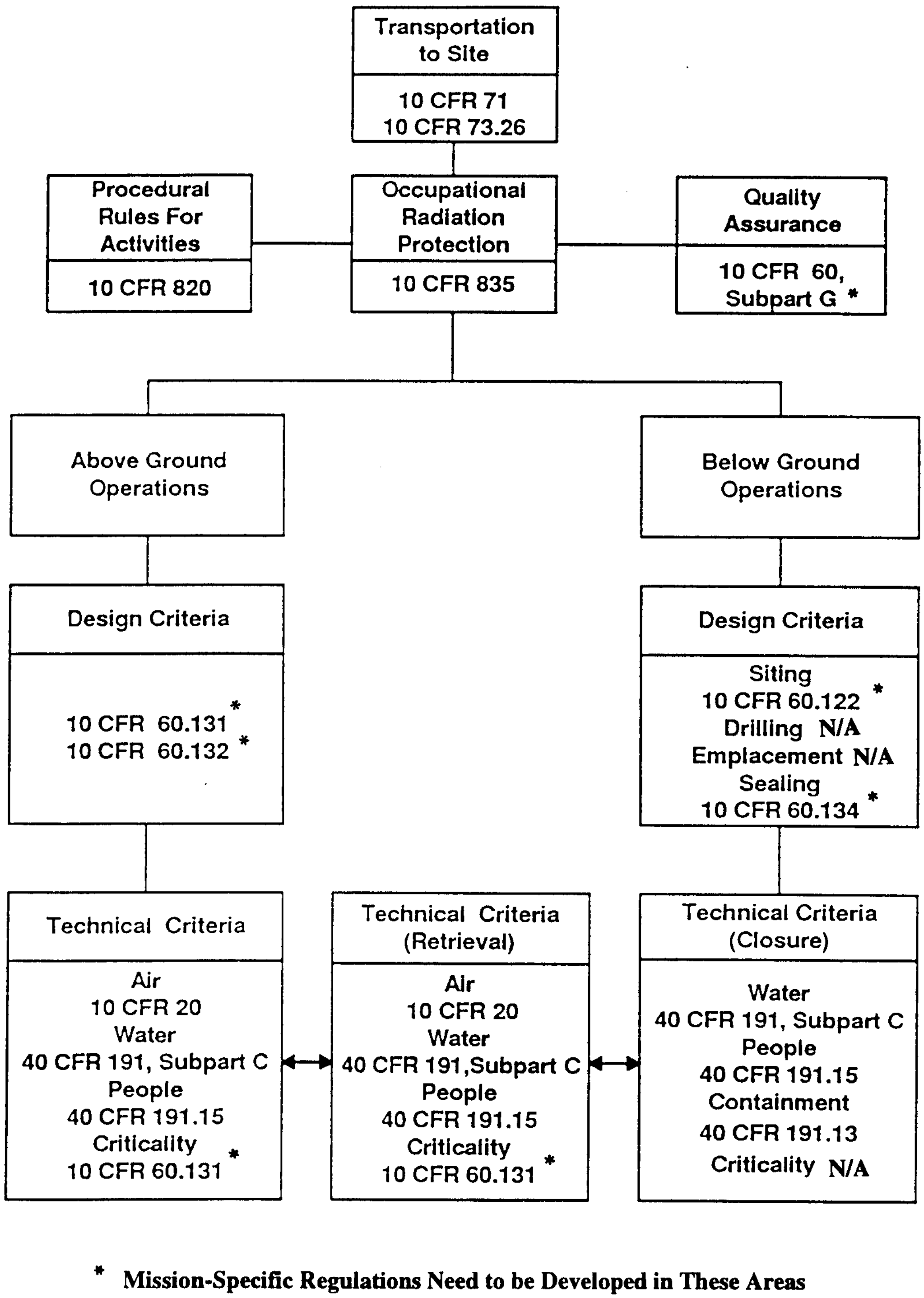

Figure 1.2.3.1-1. Existing Regulations that May Apply to a Deep Borehole Disposal Facility.

2. DEEP BOREHOLE DISPOSAL FACILITY DESCRIPTION

2.1 General Facility Description

2.1.1 Functional Description

The Deep Borehole Direct Disposal Facility Option supports the Fissile Materials Disposition Program by providing a permanent disposal option for excess weapons plutonium through emplacement in deep boreholes. This facility is a stand-alone plant that receives feed material as either plutonium metal and/or plutonium dioxide disposal form. The feed disposal form is prepackaged in cylindrical metal transportation primary containment vessels (PCVs) approximately 0.14 m (5.5 in.) in diameter × 0.51 m (20 in.) high at another facility at a different geographical location. The disposal form is transported to the deep borehole disposal facility by truck or rail with safeguards and security appropriate to the transportation of plutonium in this form.

The functional elements of the envisaged Deep Borehole Disposal Facility are shown in Figure 2.1.1-1. The Deep Borehole Disposal Facility consists of a Surface Processing Facility for receiving the disposal form in primary containment vessels contained within transportation shipping casks and repackaging the disposal form in emplacement canisters; a drilling facility for drilling the borehole and casing and sealing hydraulically-conductive features in the host rock; an Emplacing–Borehole Sealing Facility for connecting the canister modules together into long canister strings, emplacing and grouting them in place within the borehole, and sealing the borehole; and a Waste Management Facility for treating the wastes generated by the borehole disposal operations. In addition, there is a Support Facility consisting of the Administration, Plant Operations, and Balance-of-Plant facilities. The Balance-of-Plant facilities include Security, Safety, and Decontamination Systems, general Shipping and Receiving, Central Warehouse, Maintenance, Electrical Power Plant, ES&H Center, Medical Center, Fire Station, Personnel Services, Water and Fuel Supply Systems, Process Steam and Gas Supply Systems, Training, and Laundries for contaminated and uncontaminated clothing.

The original feed disposal form delivered to the Deep Borehole Disposal Facility are inspected, stored, packed, and sealed in large emplacement canisters in a Surface Processing Facility. Approximately nine PCVs are packed in one 0.41 m (16 in.) outer diameter × 6.1 m (20 ft) long emplacement canister. The PCVs are not opened at any time at the deep borehole disposal facility, so there is little risk of radioactive contamination under normal operating conditions. The plutonium loading and the PCV and emplacement canister dimensions and materials are designed to prevent criticality during transportation, storage, packaging, and emplacement operations. The deep borehole design sizing parameters for the disposal of 50 t of plutonium in four deep boreholes are summarized in Table 2.1.1-1.

The deep boreholes in which the emplacement canisters are deposited are located in a borehole array area adjacent to the Surface Processing Facility. The deep boreholes are drilled by a relocatable drilling facility that moves from one drill site to another as the boreholes are drilled in sequence. The boreholes are typically 4 km deep and decrease in diameter with depth in a stepwise fashion. The Drilling Facility drills the boreholes and seals permeable zones, fractures, and near-field drilling-induced damage zones in the rock formations as they are encountered. It also installs several well casings of decreasing diameter with depth and cements the spaces between the casing and the borehole wall with cement grout. The lower 2 km of the boreholes, comprising the emplacement zone, will be located in competent host rock and will not be cased.

A separate, relocatable Emplacing–Borehole Sealing Facility will emplace the canisters in the boreholes in the sequence in which the boreholes are drilled. Because the duration of emplacement operations depends on the schedule of delivery of plutonium feed material to the deep borehole disposal facility, and is expected to take longer than the drilling operations, several Emplacing–Borehole Sealing Facilities may be needed for each Drilling Facility. First, the 6.1-m (20-ft) canister sections will be combined into a larger 152-m-long (500-ft) canister string by threading the current canister section to the top of the canister string that is held is place within the borehole with its top exposed above the borehole entrance. By creating long canister strings in this way, the number of trips up and down the borehole can be greatly reduced, thus reducing the total time required to completely fill the emplacement zone of the borehole.

The Emplacing–Borehole Sealing Facility will next grout the spaces between the canister strings and the borehole wall with specially formulated grouts. Thesolid aggregate in the concrete is designed to prevent settlement of the canister strings under stress before the concrete has adequately cured and acquired strength. The Emplacing–Borehole Sealing Facility will install periodic hydraulic and transport seals within the emplacement zone between canister strings and at the top of the emplacement zone. It

Table 2.1.1-1 Deep Borehole Design Sizing Parameters.

Design Parameter	Value	Unit
Geometric Parameters		
Emplacement canister OD	0.41 (16)	m (in.)
Emplacement canister ID	0.38 (15)	m (in.)
Emplacement canister height	6.1 (20)	m (ft)
Primary container OD	0.14 (5.5)	m (in.)
Primary container height	0.51 (20)	m (in.)
Primary container volume	0.00779	m^3
Pu/primary container	4.5	kg
Borehole diam (2–3 km)	0.91 (36)	m (in.)
Borehole diam (3–4 km)	0.66 (26)	m (in.)
Length of canister string	152 (500)	m (ft)
Canister string volume	19.8	m^3
# Empl. canisters/canister string	25	
Emplacement zone height	2 (6,560)	km (ft)
# Canister strings/borehole	12	
# Empl. canisters/borehole	300	
Masses & Volumes		
Empl. canister sealant density	2,000	kg/m^3
Emplacement canister int. volume	0.695	m^3
Empl. zone volume/borehole	1,029	m^3
Empl. zone grout vol/borehole	791	m^3
Isolat. zone grout vol/borehole	1,538	m^3
Empl.+ isolat. zone vol/borehole	2,330	m^3
Rock volume removed/borehole	3,337	m^3
Borehole drilling criterion	15.00	%
Total Pu mass to be disposed	50.00	t
Borehole Emplacement Design		
Pu linear loading	6.00	kg/m
Primary container arrangement	3	
Primary container sets/empl. canister	3	4
Primary container axial spacing	1.524	m
Primary containers/empl. canister	9	
Mass of Pu/empl. canister	40.50	kg
Mass of Pu/canister string	1012.5	kg
Mass of Pu/borehole	12.15	t
# Boreholes (exact)	4.12	
# Boreholes (rounded)	4	
Actual Pu disposal capacity	48.60	t
# Canister strings	48	
# Emplacement canisters	1,200	
# Primary containers	10,800	
Total empl. canister sealant	750	m^3
Total emplace. zone grout	3,165	m^3
Total isolation zone grout	5,628	m^3
Total empl. + isolat grout	9,318	m^3
Total rock removed	13,357	m^3
Criticality coeff.(1) for dry sealant	0.80	
Criticality coeff.(1) for wet sealant	0.83	

(1) Criticality coefficient for dry/wet bentonite sealant inside canister and wet grout around canister in borehole.

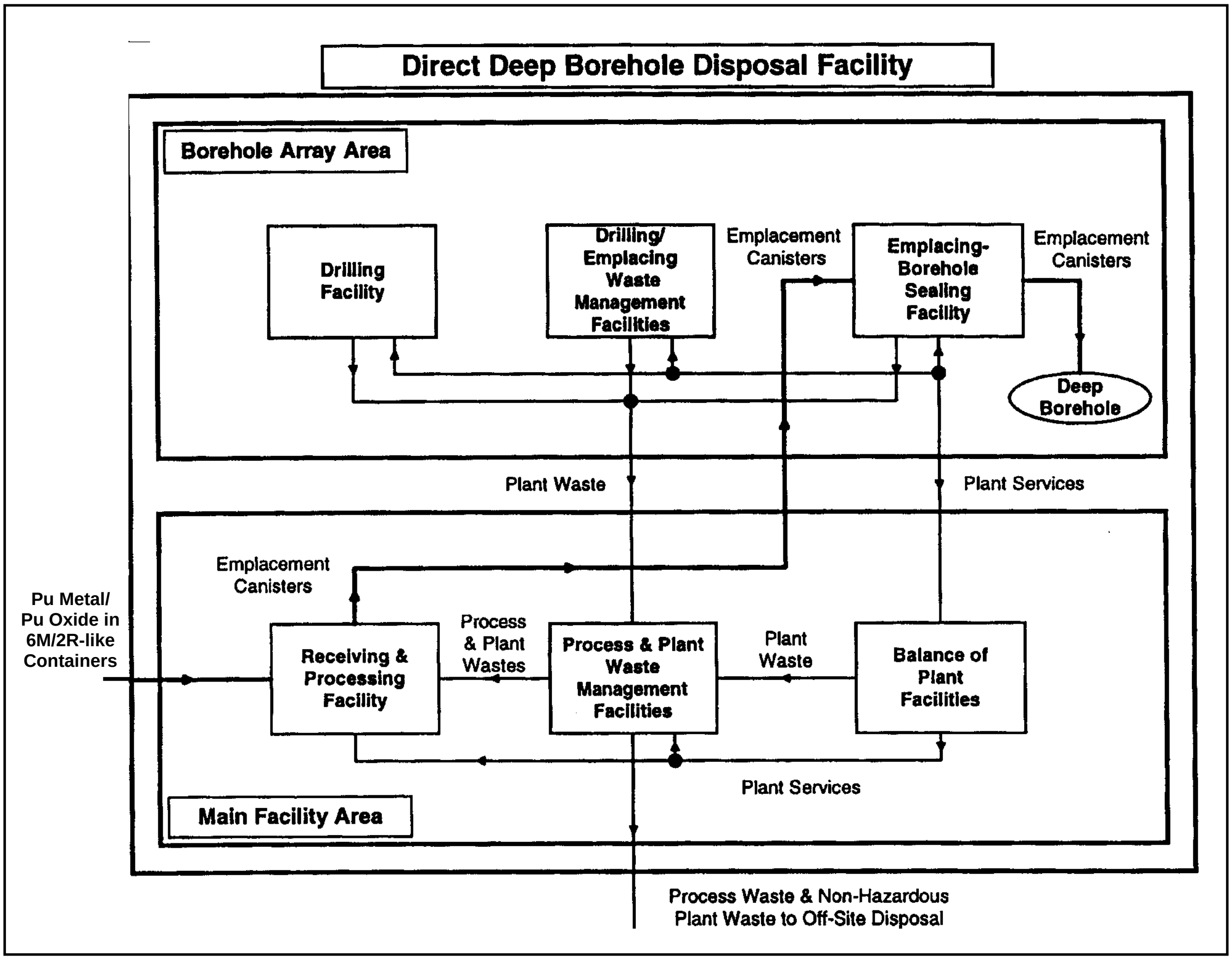

Figure 2.1.1-1. Deep Borehole Disposal Facility Flow Diagram.

will also backfill the borehole to the surface with sealing grout and will finally install a security and anti-water infiltration concrete cap at the top of the borehole at the ground surface.

2.1.2 Deep Borehole Disposal Facility Plot Plan

Figure 2.1.2-1 shows a general perspective view of the Deep Borehole Disposal Facility. Detailed descriptions of individual buildings are given in Section 2.1.3. This figure conveys general information only.

The Site Plan of the Deep Borehole Disposal Facility, given in Figure 2.1.2-2, shows in detail the layout of the facility in both the Main Facility and Borehole Array Areas. It also shows the access routes for off-site transportation and the two on-site transportation routes for trucks bearing plutonium. Figure 3.1.7-1 shows the Security Boundaries and Buffer Zone surrounding the facility. It also shows the 4 boreholes required by this design and the spacing between the boreholes in the array.

For the purpose of preparing this document, no site-specific data can be given an actual site because no specific site has been selected. Instead, the data provided is for a generic example site. The generic site map is given later in Figure 3.1.7-1. The general features of the facility site are a Main Facility, comprising a Surface Processing Facility, administration buildings, and other support facilities in the southern part of the site, and a Borehole Array area with the Drilling and Emplacing–Borehole Sealing Facilities located in the northern part. The surface processing and waste treatment areas in the southeast quarter of the facility are located as far as possible from the administration and personnel services areas, which are located in the southwest quarter. The railway and truck road connections are from the southeast, and have ready access to the plutonium receiving area of the Surface Processing Facility, the warehouses at the site, and the drill-

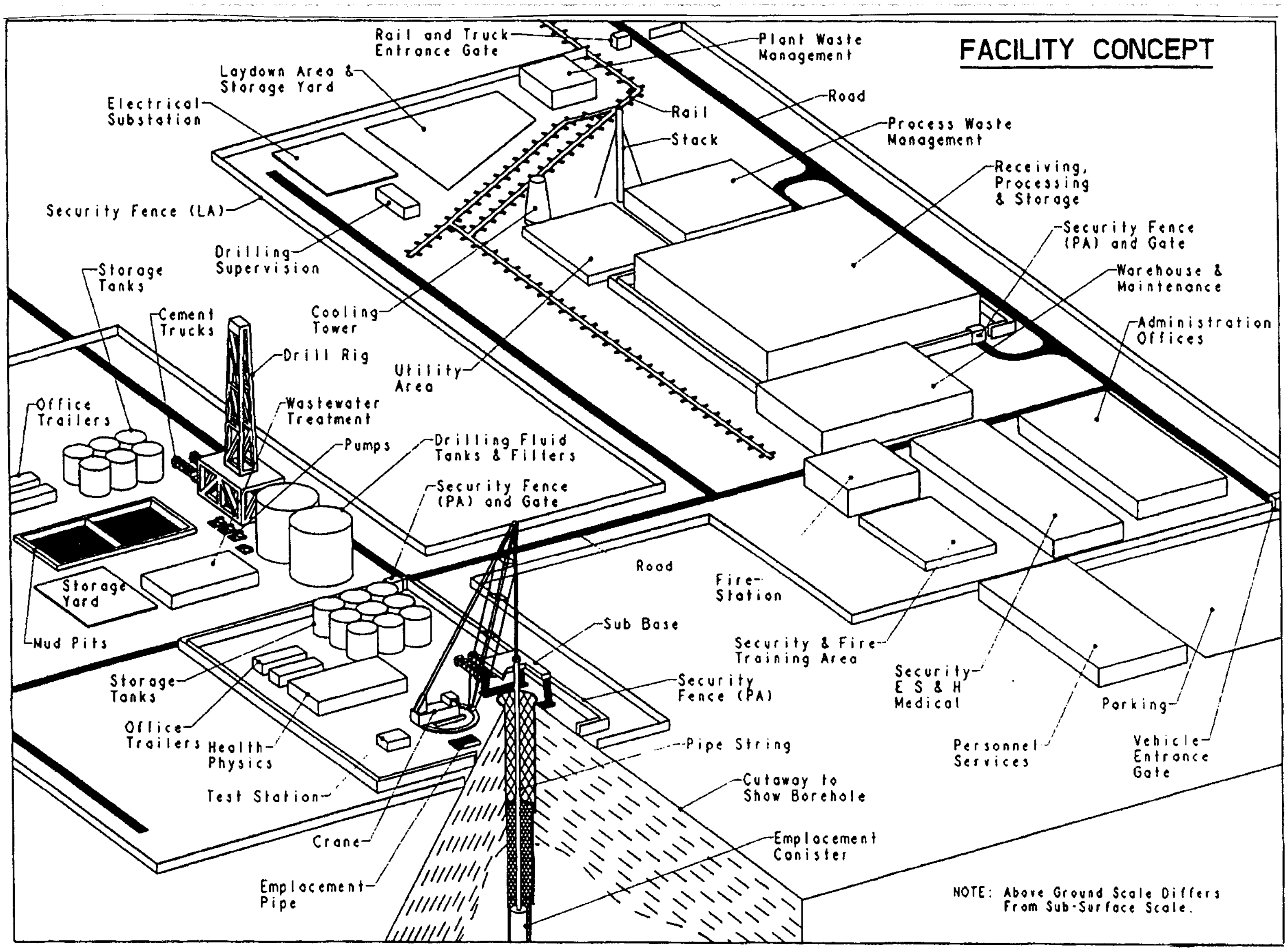

Figure 2.1.2-1. Perspective View of the Deep Borehole Disposal Facility.

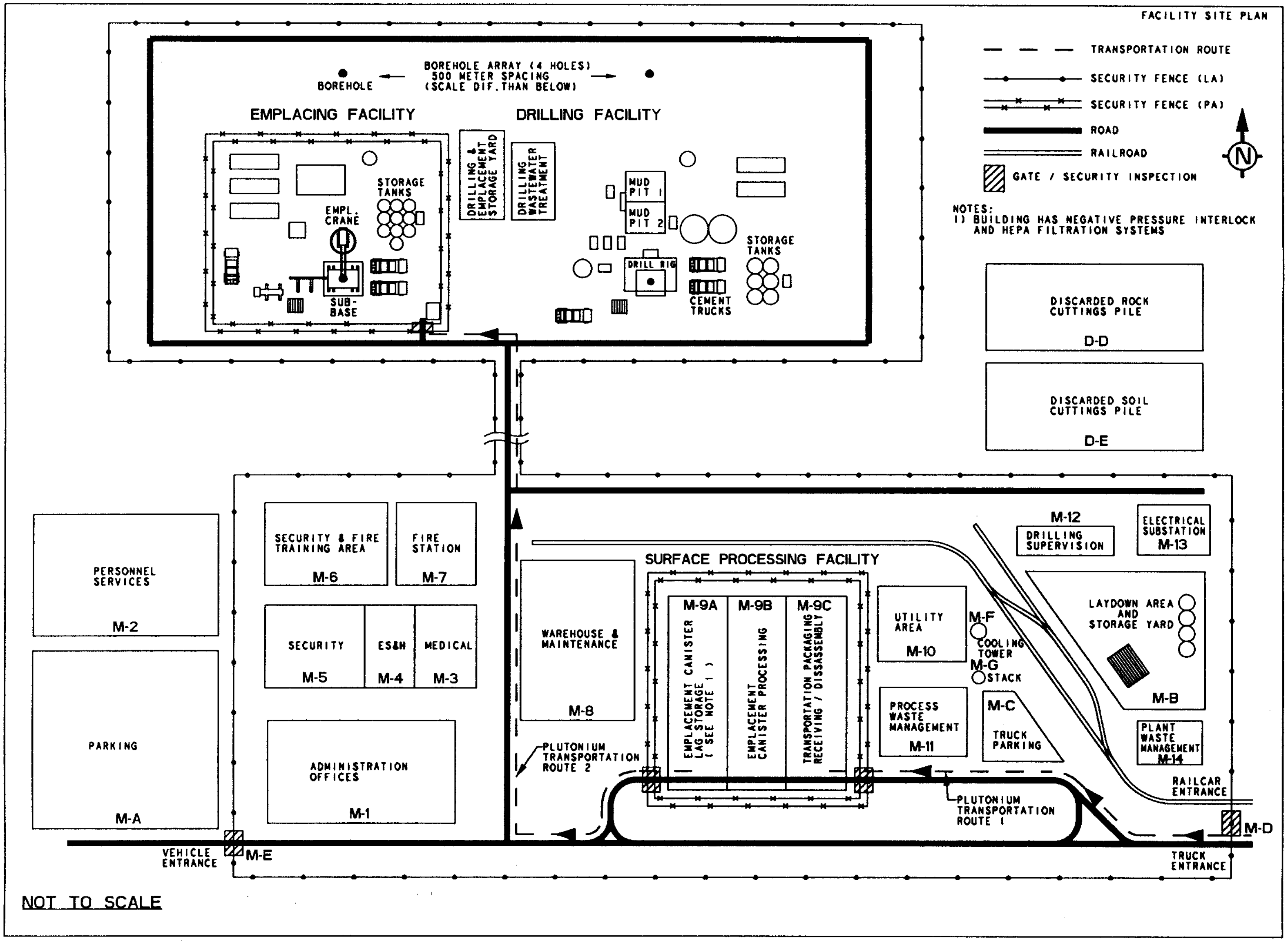

Figure 2.1.2-2. Deep Borehold Disposal Facility Site Plan Detail and Plutonium Transportation Routes.

ing materials laydown area; passenger traffic access is from the southwest of the site. The roads have been routed to provide unrestricted access to truck traffic plying between the Surface Processing Facility, the drilling materials laydown area, and the Borehole Array while avoiding the administration and personnel services areas with passenger traffic.

The Site Map in Figure 3.1.7-1 also shows security boundaries: the Protected Areas (PA), the Limited Areas (LA), and the Property Protection Areas (PPA) of the Deep Borehole Disposal Facility. The Surface Processing Facility, in which plutonium is received and stored, and the Emplacing–Borehole Sealing Facility, to which the emplacement canisters are brought from the Surface Processing Facility, are within separate Protected Areas (PA). Each PA is secured with a double fence and intruder-detection systems. The PA and operations involving classified materials are contained within the Limited/Area (LA). The Property Protection Area (PPA), bounded by the Site Perimeter Fence, surrounds the LA and includes a 1.6-km-wide (1-mile) buffer zone surrounding the facility. The passenger vehicle parking and passenger services (e.g., cafeteria, training) facilities are located outside the LA but within the PPA. Access to the site is controlled at the guardhouses located at both the Site Perimeter Fence and at the Security Fence surrounding the LA and PA areas of the Main Facility. Passenger traffic to the Main Facility is controlled at the east gates, while rail and truck traffic are controlled at the west gates. Access to the Borehole Array, which is entirely within the LA, is permitted only to traffic arriving from the Main Facility area. Access to the Surface Processing Facility and the Emplacing–Borehole Sealing Facility is controlled at guardhouses located at the PA perimeter fences surrounding these facilities.

A Ventilation Exhaust Stack discharges ventilation air from the Receiving and Processing Building (i.e., the Surface Processing Facility) and from the Process Waste Treatment System in the Waste Treatment Building. Other sources of airborne emissions at the site are the boiler stack at the Support Utilities Building and the HVAC exhaust outlets from the non-process support buildings. All non-process liquid effluents from the site are treated in the Sanitary and Utility Waste Treatment Systems in the Waste Treatment Building.

Under normal operating conditions, there will be no significant atmospheric emissions from the Deep Borehole Disposal Facility. For safety, however, two radiation and air-quality monitoring towers will be installed at the site. Groundwater will be periodically sampled, in both on-site and distant off-site monitoring wells, and will be analyzed for radioactivity emanating from the surface facilities and from the emplaced disposal form in the deep boreholes. Certain of these wells may continue to be monitored for a few years beyond closure to verify satisfactory performance in the initial part of the post-closure performance period.

2.1.3 Building Descriptions

The Deep Borehole Disposal Facility will be designed with site-specific design criteria and will comply with DOE orders and applicable NRC regulations covering the design, construction, and safety of non–nuclear reactor plutonium facilities. The facility will incorporate the safety, security, and environmental protection considerations required by DOE orders and applicable NRC and EPA regulations. Facility data is given in Table 2.1.3-1; the buildings are described in the following subsections.

2.1.3.1 Receiving and Processing

A Surface Processing Facility is provided for receiving the Pu/PuO_2 disposal form from an off-site facility, for interim storage of the received plutonium materials, and for loading emplacement canisters with the plutonium disposal form and sealing the canisters. A plot plan of the Surface Processing Facility is given in Figure 2.1.3.1-1.

2.1.3.2 Waste Management

A Process Waste Management Facility is provided for treating the Process Radwastes and Process Wastewater generated by the borehole disposal operations in the Borehole Array Area. A plot plan of the Waste Management Facility is given in Figure 2.1.3.2-1. In addition, a Plant Waste Management Facility is provided in the Main Facility Area for Health, Utility, and Sanitary Waste.

2.1.3.3 Administration

The Administration building houses administrative and engineering offices, a central records storage area, meeting and conference rooms, and human resources offices. It also houses accounting and computer facilities used for administrative/payroll operations and records storage, control mail facility, public information display, and miscellaneous storage and service areas.

2.1.3.4 Personnel Services

The personnel services building is a single-story structure that houses a 200-seat cafeteria and a multipurpose training facility.

Table 2.1.3-1. Deep Borehole Disposal Facility Data.

Building Name	Building Code	Footprint (m^2)	Number of Levels	Special SNM Materials	Construction Type
Main Area Facilities					
Administration	M-1	1,394	1	None	Light Steel
Personnel Services	M-2	1,394	1	None	Light Steel
Medical Center	M-3	929	1	None	Light Steel
ES&H	M-4	929	1	None	Light Steel
Security Center	M-5	1,858	1	None	Light Steel
Security & Fire Training Area	M-6	929	1	None	Open Area
Fire Station	M-7	929	1	None	Light Steel
Warehouse & Maintenance	M-8	2,323	1	None	Light Steel Frame
Receiving and Processing	M-9	5,295	2	SNM	Concrete
Plant Utilities	M-10	929	1	None	Masonry
Process Waste Management	M-11	1,742	1	SNM, SNM Wastes	Concrete
Drilling & Emplacing Operations Center	M-12	929	1	None	Light Steel Frame
Electrical Substation	M-13	650	1	None	Concrete Pad
Plant Waste Management	M-14	650	1	None	Light Steel Frame
Employee Parking	M-A	2,323	1	None	Asphalt
Laydown Area & Storage Yard	M-B	5,574	1	None	Open Area
Truck Parking	M-C	929		None	Asphalt
Truck & Rail Security Portals	M-D	28	1	None	Masonry
Passenger Vehicle Portal	M-E	47	1	None	Masonry
Cooling Tower	M-F	743		None	Steel
Gas Stack	M-G	37		None	Steel
Drilling Facilities		46,450			
Drill Rig	D-1	1,858	1	None	Steel Frame
Drilling Shift Office Trailers	D-2	1,858	1	None	Trailer
Cement Trucks	D-3	139	1	None	Vehicles
Cement & Water Storage Tanks	D-4	465	1	None	Steel Tanks
Compressor Station	D-5	47	1	None	Concrete Pad
Potable Water Tank	D-6	47	1	None	Stainless Steel
Drilling Fluid Tanks	D-7	465	1	None	Steel
Treated Water Storage	D-8	3,716	1	None	Steel, Concrete
Generator Truck	D-9	70	1	None	Vehicle
Drilling & Emplacing Storage Yard	D-A	929	1	None	Concrete

Table 2.1.3-1. Deep Borehole Disposal Facility Data (Continued).

Building Name	Building Code	Footprint (m^2)	Number of Levels	Special SNM Materials	Construction Type
Drilling Wastewater Treatment	D-B	186	1	None	Steel Frame
Drilling Mud Pits	D-C	7,432	1	None	Earth
Mud & Water Pumps	D-D	47	1	None	Concrete Pads
Pipe Storage	D-E	186	1	None	Packed Earth
Emplacing Facilities		46,450			
Emplacing Crane	E-1	1,858	1	None	Steel Frame
Radiation Monitoring	E-4	93	1	None	Light Steel Frame
Containment Structure	E-5	279	1	SNM Waste	Heavy Steel Enclosure
Emplacing Sub-Base	E-6	186	1	SNM Waste	Steel Frame
Emplacing Shift Office Trailers	E-7	1,858	1	None	Trailer
Storage Tanks	E-8	186	1	SNM Waste	Steel
Compressor Station	E-9	47	1	SNM Waste	Concrete Pad
Generator Truck	E-10	70	1	SNM Waste	Earth
Cement Trucks	E-11	139	1	SNM Waste	Earth
Potable Water Tank	E-12	47	1	SNM Waste	Steel
Pipe Handling Crane	E-13	139	1	SNM Waste	Packed Earth
Process Water Storage	E-14	93	1	SNM Waste	Steel Tank
Waste Monitoring & Testing Station	E-15	47	1	SNM Waste	Light Steel Frame
Entrance Security Portal	E-16	9.3	1	None	Masonry

The major functional areas of the cafeteria are the dining room, scramble-type serving area, dishwashing area, food receiving, storage, staging, preparation area, and a waste-handling area. The cafeteria is operated by a private commercial vendor and is capable of 24-hr operation.

The major functional area of the training facility includes several multiuse training rooms and equipment storage rooms. Additional training areas are available in the dining areas of the cafeteria during off hours.

2.1.3.5 Central Warehouse

The Central Warehouse is a metal building attached to Central Shipping and Receiving. The Central Warehouse is provided for storage of equipment, parts, and other plant supplies required for routine use.

A HEPA filter testing area will be included to provide for storage and testing of HEPA filters and storage of respirator cartridges.

2.1.3.6 Drilling and Emplacing–Borehole Sealing Operations Center

The Drilling and Emplacing–Borehole Sealing Operations Center, located in the northeast corner of the main facility area, provides a consolidated area for control of the Drilling and Emplacing–Borehole Sealing activities of the facility. This center contains electronic data systems that support monitoring and control of the Drilling and Emplacing–Borehole Sealing systems and support facilities that are considered vital to the safety and security of these facilities. The center is manned by the Drilling Shift Superintendent and the Emplacing–Borehole Sealing Shift Superintendent. Their responsibilities include management of all emergency situations and overall management and coordination of activities in their respective facility areas of the borehole array.

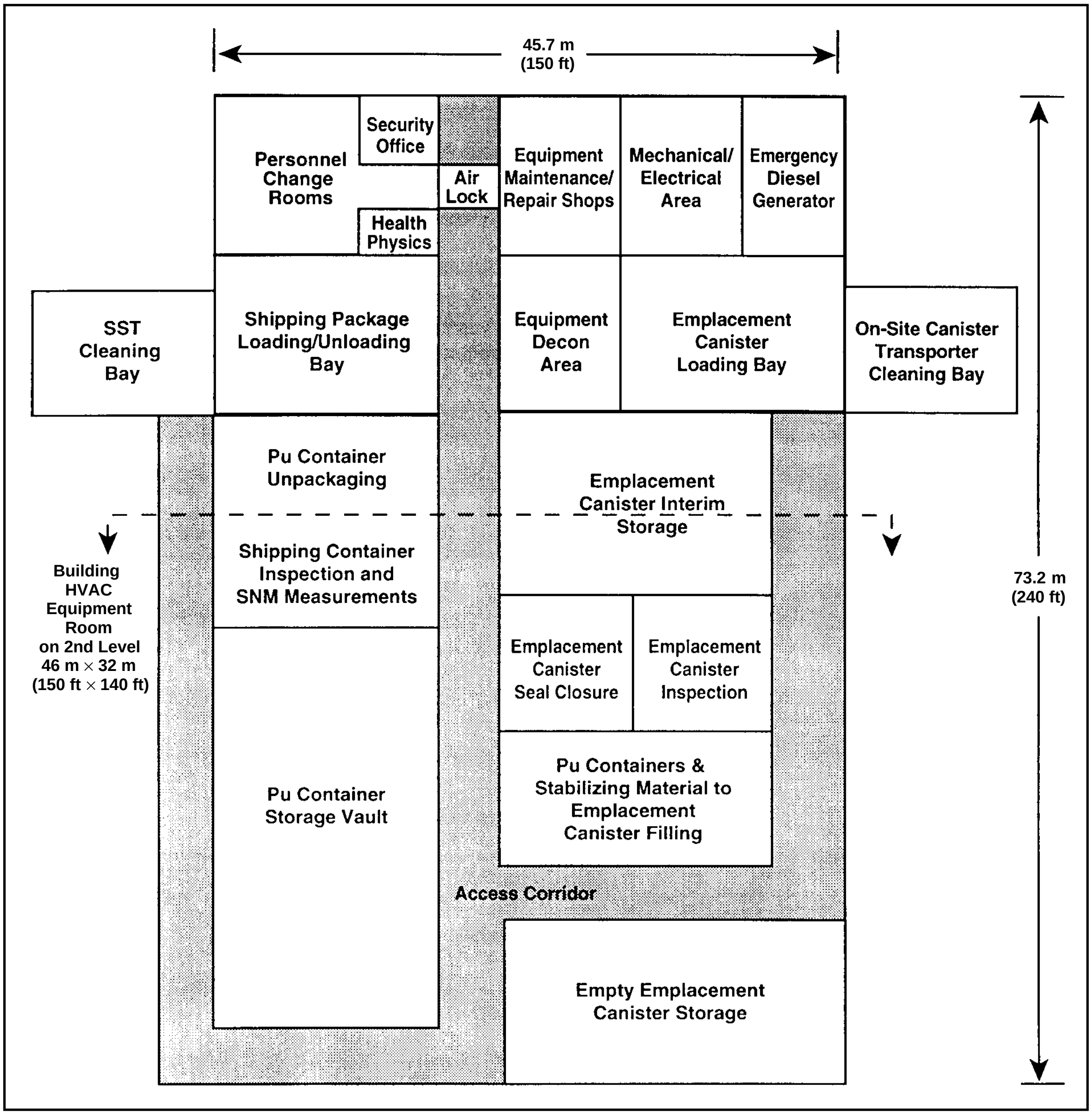

Figure 2.1.3.1-1. Surface Processing Facility—Receiving Sub-Facility Plot Plan.

2.1.3.7 Plant Utilities

Electrical Power

The electrical load for the total facility is approximately 5 MVA, supplied from an electrical utility via a high-voltage transmission line. This line terminates in a electrical power switchyard, located in the northeast corner of the main facility area, where the voltage is transformed to facility distribution levels. Power is provided to the borehole array area by low-voltage overhead lines.

High-voltage buses in the Electrical Substation are installed overhead on steel or concrete structures. Surge voltage protection equipment, potential transformers, current transformers, and equipment for relaying and metering are installed on the high-voltage bus, the circuit breakers, and the transformers. The switchyard breakers are selected with appropriate interruption rating compatible with the fault current available from the transmission system. Power is distributed to the Main and Borehole Array Areas by underground cables.

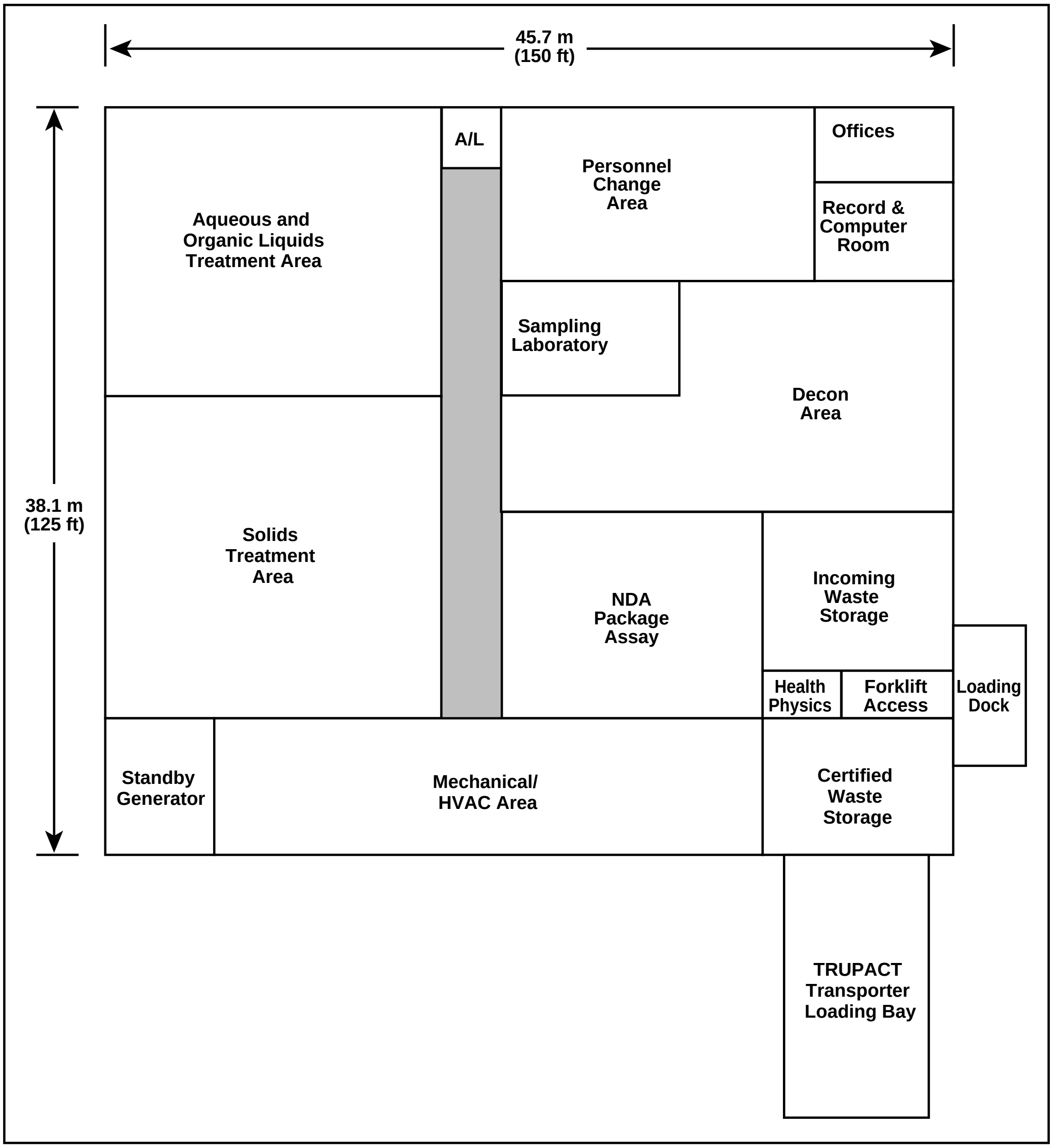

Figure 2.1.3.2-1. Process Waste Management Facility Plot Plan.

Emergency Power

Emergency power is provided by diesel generators located in the facility utility area. Emergency power will be provided for the safety class loads.

2.1.3.8 Security Center

The Security Center serves as the security administrative headquarters and contains a pistol firing range, an armory, lockers, change rooms, training and meeting rooms, offices, and a storage room for supplies.

2.1.3.9 Environmental, Safety, and Health

Environmental, Safety, and Health is a fully equipped laboratory provided to perform analyses for utilities monitoring and control, environmental emissions and effluents monitoring, waste characterization, and health physics and industrial hygiene monitoring. Tests performed include radiochemistry (alpha, beta, and gamma radiation) and chemical analyses as needed. External dosimetry laboratories, radiation instrument laboratories, and a source-calibration area are included. The building also includes offices and office support areas and common use spaces such as lunch/break room and change/restrooms.

2.1.3.10 Medical Center

The Medical Center provides limited medical and wellness care services and is particularly needed because of the likelihood of the Deep Borehole Disposal Facility being located in a remote area. Seriously injured or contaminated employees are externally decontaminated and are evacuated to a local emergency facility. This facility provides space for various medical services, such as first aid, dispensary, physical examinations, x-ray and EKG, and laboratory space for various testing services and physical/industrial therapy. Office space for medical staff and records is included. Additional toilet facilities are provided for the employee drug testing program.

2.1.3.11 Fire Station

The Fire Station is provided to house the fire department fire engines, ambulances, and other emergency vehicles and emergency personnel.

2.1.3.12 Emplacing Shift Office Trailers

Offices and other facilities will be available for management and employees at the canister emplacing location.

2.1.3.13 Emplacing Waste Management Facility

Wastes produced during the emplacement process will be transported to, and treated in, the waste management building in the main area.

2.1.3.14 Radiation Decontamination and Monitoring

Radiation monitoring systems will be provided in the Emplacing–Borehole Sealing Facility and Main Facility Areas.

2.1.3.15 Drilling Shift Office Trailers

Offices and rest areas will be provided for the Drilling and Emplacing–Borehole Sealing Facilities for employee convenience.

2.2 DESIGN SAFETY

2.2.1 Earthquake

All plant structures, systems, and components (SSCs) will be designed for earthquake-generated ground accelerations in accordance with UCRL-15910 (DOE-STD-1020-92), *Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena Hazards*.

Under this guidance, the applicable seismic hazard exceedance probability of 2×10^{-3} for General Use (Performance Category 1), 1×10^{-3} for Low and Moderate Hazard (Performance Categories 2 & 3), and 2×10^{-4} for High Hazard (Performance Category 4) SSCs will be used.

Seismic design considerations for Performance Category 3 and 4 SSCs will include provisions for such SSCs to function as hazardous materials confinement barriers and also for adequate anchorage of building contents to prevent their loss of critical function during an earthquake. In essence, design considerations avoid premature unexpected loss of function and attempt to maintain ductile behavior in structures during earthquakes.

Characteristics of the lateral force design are as important as the magnitude of the earthquake load used for design. These characteristics include redundancy, ductility, the combining of elements to behave as a single unit, adequate equipment anchorage, allowance for the effect of nonuniformity and asymmetry in structures and equipment, detailing of connections and reinforced concrete elements, and the use of specified materials in their construction.

In addition to structural safety, proper operation of emergency systems during and after an earthquake is essential. The fire protection system, emergency power, water supplies, and the controls for safety class equipment are examples of plant systems that must be available following an earthquake. As stated in Chapter 4 of DOE-STD-1020-92, under Survival of Emergency Systems, "…earthquake-resistant design considerations extend beyond the dynamic response of structures and equipment to include survival of systems that prevent facility damage or destruction due to fires or explosions."

2.2.2 Wind

All new plant structures, systems, and components (SSCs) will be designed for wind or tornado load criteria in accordance with DOE-STD-1020-92 and the corresponding facility usage and performance goals. Wind loads will be based on the annual probability of exceedance of

2×10^{-2} for General and Low Hazard (Performance Categories 1 & 2), 1×10^{-3} for the Moderate Hazard (Performance Category 3), and 1×10^{-4} for the High Hazard (Performance Category 4) SSCs. Sites for which tornadoes are the viable wind hazards will be designed for the annual probability of exceedance of 2×10^{-5}, as defined in Table 5-3 of DOE-STD-1020-92.

Wind design criteria will be based on annual probability of exceedance, importance factor, missile criteria, and atmospheric pressure change as applicable to each performance (usage) category as specified in Table 5-2 of DOE-STD-1020-92.

As stated in DOE-STD-1020-92, characteristic safety considerations will be reflected in the design of the system in that, "…the main wind-force resisting system must be able to resist the wind loads without collapse or excessive deformation. The system must have sufficient ductility to permit relatively large deformations without sudden or catastrophic collapse. Ductility implies an ability of the system to redistribute loads to other components of the system when some part is overloaded."

2.2.3 Floods

All facilities and buildings should preferably be located above the critical flood elevation (CFE) from the potential flood source (river, dam, levee, precipitation, etc.), or the site/facility will be hardened to mitigate the effects of the flood source such that performance goals are satisfied. Emergency operation plans will be developed to safely evacuate employees and secure areas with hazardous, mission-dependent, or valuable materials. The extent of the flood hazard will be determined using the appropriate usage (performance) category for determining the "Annual Hazard Probability of Exceedance" of 2×10^{-3} for General Use (Performance Category 1), 5×10^{-4} for Important or Low Hazard (Performance Category 2), 1×10^{-4} for Moderate Hazard (Performance Category 3), 1×10^{-5} for High Hazard (Performance Category 4), facility as defined in Chapter 6 of DOE-STD-1020-92. For moderate- and high-hazard facilities located below the design basis flood (DBFL) elevation, the design must be developed so that continued facility operation is provided.

The CFE will be determined by obtaining the appropriate DBFL. The DBFL is the peak hazard level (flow rate, depth of water, etc.) corresponding to the mean "Annual Hazard Probability of Exceedance" or combinations of flood hazards (river flooding, wind–wave action, etc.) and corresponding loads associated with peak hazard level and applicable load combinations (hydrostatic and/or hydrodynamic forces, debris loads, etc.).

Site drainage must comply with the regulations of the governing local agency. The minimum design level for the Storm Water Management System is the 25-yr, 6-hr storm, but potential effects of larger storms up to the 100-yr, 6-hr storm will also be considered. However, Storm Water Management Systems must prevent the CFE from being exceeded. Accordingly, for some facilities, Storm Water Management Systems may have to be designed for more extreme storms.

Whenever possible, all facilities in performance categories above the General Use Category (Performance Category 1) will be constructed with the lowest floor of the structure, including subsurface floors, above the level of the 500-yr flood. This requirement can be met by siting and/or flood protection. Whenever possible, all facilities, including their basements in all performance categories, will be sited above the 100-yr flood plain (DOE 6430.1A, Section 0111-2.5).

2.2.4 Fire Protection

The fire protection systems of the plant and its associated support buildings will be in accordance with DOE orders and National Fire Protection Association codes and standards.

Redundant firefighting water supplies and pumping capabilities (electric motor drivers with diesel backup) will be installed to supply the automatic and manual fire protection systems located throughout the site. One supply tank and one set of pumps will be designated to meet Design Basis Earthquake requirements. Appropriate types of fire protection systems will be installed to provide life safety, prevent large-loss fires, prevent production delay, ensure that fire does not cause an unacceptable on-site or off-site release of hazardous material that will threaten the public health and safety or the environment, and minimize the potential for the occurrence of a fire and related perils.

Specific production areas and/or equipment will be provided with the appropriate fire detection and suppression features as required with respect to the unique hazard characteristics of the product or process.

A fire hazards analysis will be performed to assess the risk from fire within individual fire areas of the facility.

All sprinkler water that has been discharged in the Surface Processing Facility and the Emplacing–Borehole Sealing Facility will be contained, monitored, sampled, and (if required) retained until it can be disposed of safely.

2.2.5 Safety Class Instrumentation and Control

The safety classification of instrumentation and controls will be derived from the safety functions performed. This safety classification is based on DOE Orders 6430.1A and 5481.1B.

Safety class instrumentation will be designed to monitor identified safety-related variables in safety class systems and equipment over expected ranges for normal operation and accident conditions and for safe shutdown. Safety class controls will be provided, when required, to control these variables.

Suitable redundancy and diversity will be used when designing safety class instrumentation to ensure that safety functions can be completed, when required, and that a single-point failure will not cause loss of protective functions. Redundant safety class signals must also be physically protected or separated to prevent a common event from causing a complete failure of the redundant signals. IEEE 379 and IEEE 384 provide the design bases for redundancy and separation criteria. Safety class instrumentation will be designed to fail in a safe mode following a component or channel failure. Safety class UPS power will be provided when appropriate.

2.2.6 Nuclear Criticality

2.2.6.1 Criticality Safety of Surface Operations

The design of the Deep Borehole Facility will include the basic controls for assuring nuclear criticality safety in the Surface Processing Facility and the Emplacing–Borehole Sealing Facility, during on-site transportation of plutonium feed material between the site perimeter and the Surface Processing Facility, and during transportation of processed plutonium from the Surface Processing Facility to the Emplacing–Borehole Sealing Facility. The process designs will satisfy the double-contingency principle; that is, "…process designs shall incorporate sufficient safety factors so that at least two unlikely, independent, and concurrent changes in process conditions must occur before a criticality accident is possible…" from DOE Order 6430.1A. Basic control methods for the prevention of nuclear criticality include the following:

1. Provision of safe geometry (preferred).

2. Engineered density and/or mass limitation.

3. Provision of fixed neutron absorbers.

4. Provision of soluble neutron absorbers.

5. Use of administrative controls.

Although geometric controls are used extensively wherever practical, there are cases in which geometric control alone cannot practically provide assurance of criticality safety. In these cases, engineered controls can be used to control neutron moderation, neutron-absorbing poisons, and the mass and concentration/density of the materials.

2.2.6.2 Criticality Regulations for Surface Processing

Technical criteria for criticality safety in Surface Processing Facility Operations will be mission-specific but may be based on HLW requirements given in 10 CFR 60.131(b)(7): "All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (K_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation." That is, the criticality safety requirement specified in this document is that the effective criticality coefficient be maintained at a value less than 0.95.

2.2.6.3 Post-Emplacement Downhole Criticality Safety

In the context of the present deep borehole disposal facility design, downhole criticality safety events that are of concern can be classified into three broad categories as follows:

Category 1. Criticality in Undisrupted Emplacement Configuration.

Category 1.1. Criticality in undisturbed initial emplacement configuration.

Category 1.2. Criticality in emplacement configuration disturbed only by material property alterations.

Category 2. Criticality in Disrupted Emplacement Configurations.

Category 2.1. Criticality in emplacement accident configurations.

Category 2.2. Criticality in disrupted configurations due to natural phenomena.

Category 3. Criticality Due to Geochemical Reconcentration.

Category 3.1. Criticality due to geochemical reconcentration in borehole.

Category 3.2. Criticality due to geochemical reconcentration in geosphere.

In this canistered design concept, criticality of the plutonium in the emplacement configuration is to be controlled and prevented by appropriate choice of the plutonium loading in the emplacement canisters for the design dimensions, spacing, and arrangement of the PCVs within the emplacement canister, the spacing between the emplacement canisters, and the composition-dependent nuclear properties of the materials used in the design, including any neutron absorbers that are incorporated in the canister sealants and fillers. Thus, the criticality analyses used for designing the emplacement configuration must account for not only the presence of the fissile material within the canister, but also for the nuclear moderation, reflection, and absorption properties of the different materials. The materials that must be considered in the analyses include the sealant materials within the emplacement canister, the canister material, the sealants/concretes between the canister and the borehole wall, and the properties of some portion of the host rock itself. In particular, it is necessary to consider the moderating effects of hydrogen in the bound water in the concrete/grouts and the brine invading the interstitial pore space of all materials external to the emplacement canister.

In addition to the above analyses required to establish criticality safety at the time of initial emplacement, additional short-term, intermediate-term, and long-term scenarios will have to be considered to evaluate criticality safety under normal operating and natural event–induced accident conditions. Long-term criticality evaluations are necessary because both ^{239}Pu and its alpha-decay product ^{235}U are fissile and very long lived (half lives 24,400 yr. and 7.1×10^8 yr., respectively). In particular, it is necessary to consider short-term scenarios in which the emplacement configuration remains unaltered, but the flow barriers to brine influx from the surrounding geosphere have failed. Owing to any one of a number of possible mechanisms such as corrosion, stress-corrosion cracking, and disruption by earthquakes, even the most corrosion-resistant canisters are likely to fail after a relatively short time of, say, 200 years. This is particularly true because of the high temperature (120–150°C) and high salinity (as much as 30%) of the brines within a deep borehole. Consequently, the entire borehole, including the canister, the interstitial pore space of the concrete, the sealants, and the plutonium disposal form, will become saturated with brine from the external environment. The plutonium disposal form, the spacing, and the geometric configuration of emplacement must be designed to be safe under such a scenario. Furthermore, it is necessary to consider additional long-term scenarios in which the geometric configuration at emplacement is completely disrupted, the plutonium in the disposal form is redistributed (by physical rearrangement or by leaching out by brine), and additional dissolved plutonium from another location in the borehole invades and displaces the non-plutonium-bearing brine within the pore space.

However, it is necessary to evaluate the long-term risk of criticality, within the borehole or within an undetected closely spaced set of fractures in the surrounding host rock, due to *slow but continuous* leaching of plutonium from the disposal form by recirculating brine, transport into other regions, and reconcentration at one location through continuous precipitation or sorption under different conditions of temperature and brine chemistry. The existence of sufficiently high brine flow velocities, originating from thermohaline convective instability of brine in fractures or from some other mechanism, would be necessary for such reconcentration scenarios to be of concern. However, preliminary estimates show that even moderate salinity gradients have a strongly stabilizing effect and prevent the initiation of brine circulation.

Analyses of Category 1 Criticality Events

Preliminary criticality analyses show that the design for the direct disposal of Pu/PuO_2 in compound canisters presented in this report is very robust and safe under Category 1 criticality event scenarios.

Computational Procedure

The criticality calculations were performed in the neutron-transport-only mode using Version 4a of the *Monte Carlo Neutron and Photon Transport (MCNP)* code developed by the Los Alamos National Laboratory (LANL). The high-density, pointwise continuous-energy cross sections from the LANL ENDEF-V neutron cross section library were used for the nuclear properties of the materials. This library is the most recent and appropriate for calculating the criticality coefficient K_{eff} for "slow," near-critical configurations. The calculations were performed for a uniformly emplaced 1-m section of a 0.91-m-diam (36-in.) borehole, assuming that the borehole extends to infinity in both directions parallel to its axis. The emplacement canisters are 0.41 m (16-in.) outer diameter steel cylinders with a wall thickness of 1.27 cm (0.5 in.) Because the emplacement canisters are threaded into a continuous 152-m (500-ft) canister string, the emplacement canister string was also assumed to be infinitely long for modeling purposes. Inside each emplacement canister there are sets of either one or three PCVs (13.97 cm diam, 50.8 cm height, 0.64 cm wall thickness) in axially separated horizontal planes. When there is only one PCVs per horizontal plane, it is located at the center of the emplacement canister. When there are three PCV per horizontal plane, they are arranged symmetrically at 120° angular separation around a circle. Within each PCVs there are two product cans (6.286 cm diam × 3.655 cm height) containing 2.25 kg of plutonium (19.84 g/cm^3 density). The spaces between the product cans and the PCV and the space between the PCVs and the emplacement canister are filled with bentonite sealant, which was assumed to have a porosity of 37%. Perfect reflection boundary conditions were used at the top and bottom boundaries to mimic the infinitely long borehole. Neutron transport into the granite host rock was modeled to a depth of 1 m in the radial direction, with a perfectly absorbing boundary condition imposed at the outer surface. Although neutrons arriving at this boundary leave the computational domain and do not return to it, the calculations show that the neutron flux past this boundary is reduced to negligible levels because of moderation and thermalization of the neutrons by the 1 m of granite.

The elemental compositions of the granite, bentonite canister sealant, grout, and brine used in the criticality calculations are given in Table 2.2.6.3-1. Natural abundance isotopic ratios are used for each element except the fissile materials. The emplaced plutonium was assumed to be ^{239}Pu without admixtures of ^{238}Pu and ^{240}Pu, although an isotopic composition of 93% ^{239}Pu, 6% ^{240}Pu, and 1% trace isotopes was assumed for the ceramic pellet feed in the Immobilized Disposal Deep Borehole Alternative. The presence of the ^{240}Pu at this concentration could somewhat alter the results. Also, the criticality analyses presented here do not consider the effects of production of fissile daughters of ^{239}Pu, and in particular do not include the ^{235}U produced by alpha decay.

Brine salinities as high as 500 g/L of total dissolved solids, and averaging 300 g/L, have been reported at depths of 3–4 km in crystalline rock formations with undisturbed connate water. Because the chlorine in the brine absorbs neutrons significantly, the salinity of the brine was assumed to be a conservative 50 g/L. This assumption was made to avoid taking excessive credit for neutron absorption by chlorine (which has a large neutron capture cross section)

Table 2.2.6.3-1. Chemical Compositions of Materials Used in Criticality Analyses.

Chemical Element(1)	Granite	Grout	Bentonite	Brine
Density g/cm^3	2.80	2.08	1.70	1.05
Porosity %	0.0	20.0	37.0	
Si	0.32805	0.28471	0.32000	
O	0.48604	0.53732	0.49000	0.84590
Ti	0.00234			
Al	0.07658	0.04338		
Fe	0.02482	0.01085		
Mn	0.00093			
Mg	0.00531		0.02000	
Ca	0.01422	0.07616	0.00200	0.01124
Na	0.02582	0.01598	0.03000	0.00603
K	0.03412	0.01717	0.00400	
H	0.00094	0.01618		0.10658
P	0.00083		0.00100	
Cl		0.00305		0.03025
Zr				

(1) Weight fraction of component chemical elements.

and other constituents, because the continued existence of high salinities should not be depended on to ensure criticality safety. The composition of the brine used here was obtained from measurements made at a depth of 1200 m in the deep borehole drilled at the Kola Peninsula in Russia.

The grout used to seal the space between the emplacement canisters and the borehole wall is assumed to consist of 80% by volume of NBS Ordinary Cement and 20% by volume of brine of the same composition as that in the host rock (given above). The composition of the NBS Ordinary Cement was obtained from *Criticality Calculation with MCNP, A Primer.* The grout composition given in Table 2.2.6.3-1 includes the 20% by volume of brine.

Categories 1.1 & 1.2 Criticality Analyses

Criticality events belonging to Category 1.1 relate to conditions at initial emplacement without any alteration of the emplaced materials. Criticality events belonging to Category 1.2 are related to situations in which the conditions at initial emplacement are changed by alterations in the properties of emplaced materials, particularly saturation of the sealant by brine. To investigate these two categories, two sets of calculations were performed for one and three product cans per horizontal plane for dry and brine-saturated bentonite. For each of these cases the axial separation of the PCVs was varied to alter the plutonium loading in each of the two arrangements of PCVs. The addition of neutron poisons to the sealant was not considered. The criticality coefficients for these cases are shown in Figures 2.2.6.3-1 and 2.2.6.3-2 as a function of the 2R PCV axial spacing within the emplacement canister. The plutonium loading per unit length along the borehole is also shown to provide a basis for comparing the plutonium loading between Immobilized and Direct Disposal deep borehole alternative designs.

These results show that the criticality coefficient is relatively insensitive to axial separation distance and to the number of canisters in a horizontal plane. This shows that the system is well moderated. This is also indicated by the lack of sensitivity of the criticality coefficient to brine saturation of the bentonite sealant. Thus, the criticality coefficient is determined primarily by the separation distance between the product cans and the bentonite sealant within each PCVs, and not by the separation distance between different PCVs. The criticality coefficient of $K_{eff} \approx 0.80$ for the design configuration of three 2R PCVs in a horizontal plane and an axial separation distance of 152.40 cm (i.e., 6 kg/m linear loading) is criticality safe as long as the separation between the product cans within the PCVs can be maintained.

Categories 2.1 & 2.2 Criticality Analyses

Criticality events of Category 2.1 are related to disrupted configurations that arise from accidents that occur during the emplacement of the canister strings.

1. The first accident scenario was that of an emplacement canister string falling freely into the borehole and rupturing when it hits the bottom of borehole. It was assumed that a number of product cans would be ejected from the canister and would fall in such a way that they would land stacked vertically in horizontal sets of three cans per set. It was assumed that the bottom of the borehole is filled with brine. For two sets of product cans (i.e., a total of six cans) the criticality coefficient $K_{eff} = 1.0$, while for three sets of product cans (i.e., a total of nine cans) the system was supercritical at $K_{eff} = 1.12$. Although it is not criticality safe, this accident scenario is “beyond extremely unlikely,” because the borehole will always be kept filled with water or mud during emplacement operations. The viscous drag of the solution slows the canister to such an extent that the force of impact will be too small to breach the canister.

2. A second scenario for this same accident is that, on striking the bottom, the emplacement canister would become vertically compressed and would expand sideways until it fills the borehole cross section. Thus, the canister and its contents would compress vertically by a factor of 2.25 while expanding radially by a factor of 0.1975. The criticality coefficient calculated for this case was $K_{eff} = 0.74$.

No Category 2.2 analyses were carried out to investigate the effect of natural phenomena hazards such as earthquakes. Category 2 assessments will be included in the research and development program.

Analysis of Category 3 Criticality Events

Category 3 criticality events are criticality events induced by slow geochemical reconcentration of plutonium due to the *slow but continuous* dissolution of the emplaced plutonium disposal form by flowing subsurface brines, mobilization and transport of the plutonium as a solute to another location in the borehole or the host rock mass, and reconcentration at this location due to precipitation out of solution and/or absorption from solution on the rock surfaces.

Because of the very low release rates, the process of reconcentration will require the persistence over a long

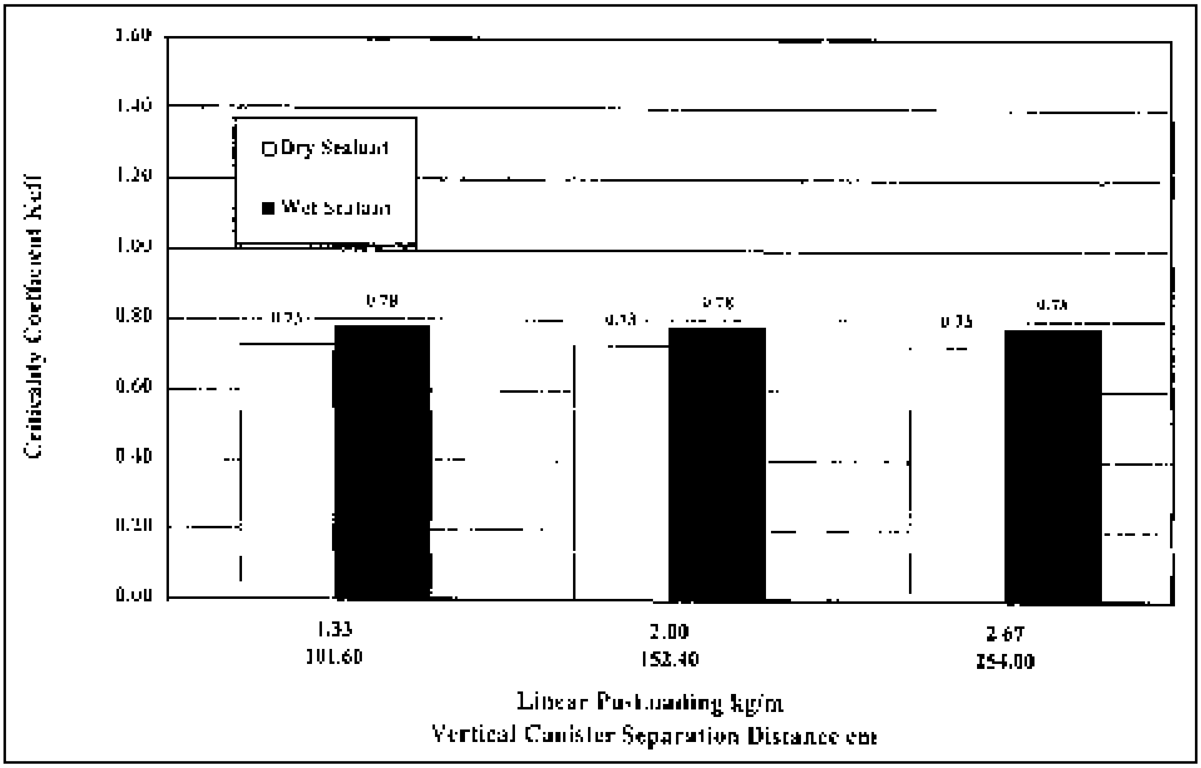

Figure 2.2.6.3-1. Criticality Analysis for One PCV in a Horizontal Plane with Sealant, Grout, and Brine in the Borehole.

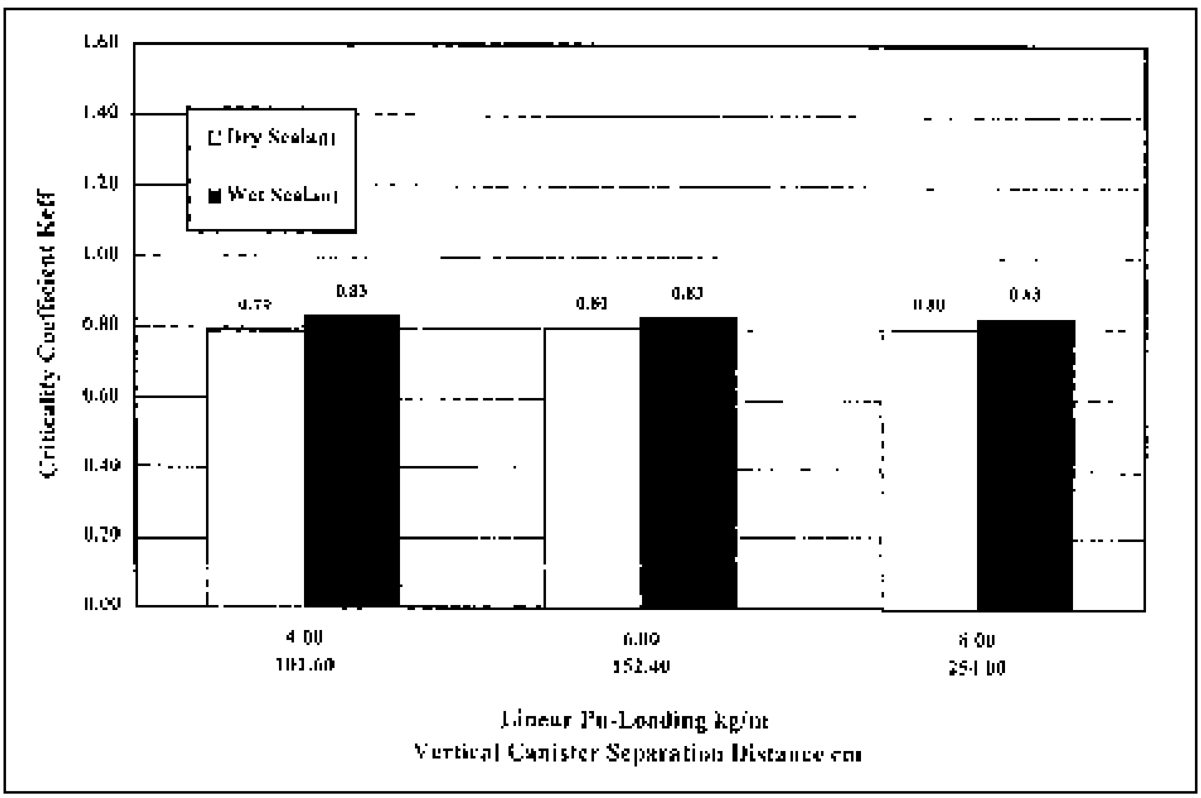

Figure 2.2.6.3-2. Criticality Analysis for Three PCVs in a Horizontal Plane with Sealant, Grout, and Brine in the Borehole.

time of continuous or episodic dissolution–reconcentration activity and the overcoming of many dissolution/reprecipitation rate limiting factors for a critical mass to form. The continuous dissolution and reconcentration process will depend on the presence of an adequate flow velocity of brine and on the existence of different temperature, pressure, and geochemical conditions favorable to dissolution at the source location and reprecipitation at the criticality location as a mineral containing either plutonium or its fissile decay products in dilute concentrations. It will also require the existence of a sufficiently large volume of appropriately configured void space in the host rock, within intergranular pores, fracture sets, or vugular cavities, for the mineral to be deposited with fissile material sufficient to form a critical mass.

If a critical mass forms in the subsurface, then depending on the kinetics of the criticality event, a substantial amount of energy may be released in the subsurface. This energy, primarily in the form of heat, would increase the temperature, generate steam, redissolve and expel the fissile material containing minerals from the critical mass along fractures, and deplete the fissile material content as a result of the fissioning process. The expulsion of water in the brine may also increase the solids concentration beyond the solubility limits and cause rapid precipitation of minerals in the fractures. Also, expulsion of water would reduce its moderating effect on neutrons, while the expulsion or precipitation of other chemical constituents of brine (such as chlorine, which is a good neutron absorber) would alter the rate of fissioning. Most, but not all, of these events are likely to lead to shutting down of the nuclear reaction quickly until the critical mass reforms slowly through geochemical reconcentration over geologic time and a criticality event recurs as one of a series of such events.

Thus, Category 3 criticality events are the result of a complex series of coupled phenomena. These events have not been analyzed in the current phase of the program. Although the occurrence of such criticality events is considered to be “beyond extremely unlikely,” they will be studied as a part of the research and development program in the future.

2.2.6.4 Regulations for Post-Emplacement Downhole Criticality

Technical criteria for criticality safety for subsurface downhole conditions have not been defined in the existing regulations. To the extent that plutonium is buried in an ancient stable rock formation, it has been speculated that the need for long-term criticality control may be minimal if the consequences of criticality to the biosphere is negligible. However, no systematic studies of downhole criticality at deep borehole conditions have been made to verify these speculative opinions. Therefore, these analyses have to be performed to permit the establishment design criteria for criticality safety in the subsurface during the preclosure emplacement operations and post-closure performance periods.

2.2.7 Ventilation

The HVAC system design for the Surface Processing and the Emplacing–Borehole Sealing facilities will meet all general design requirements in accordance with DOE Order 6430.1A, Section 1550, and with ASHRAE design guidelines.

The HVAC system provides environmental conditions for the health and comfort of personnel and for equipment protection. Typically, the ventilation system will be designed to maintain confinement to preclude the spread of airborne radioactive particulates or hazardous chemicals within the facilities and to the outside environment.

The design includes engineered safety features to prevent or mitigate the potential consequences of postulated design-basis accident events.

2.3 Safeguards and Security System Facilities

The essence of Safeguards and Security (S&S) as it relates to the deep borehole site is to help guarantee that plutonium is not diverted from the intended disposition process, that the amount of SFM delivered to the site will—within acceptable physical measurement parameters—be accountably disposed of, and that the process satisfies international (IAEA) controls and standards of verifiability. S&S activities involve setting requirements for site construction/layout, site operation, and site closure. In the following sections we describe the bounding conditions for the following:

1. Site construction/layout requirements.

2. Physical site and material protection requirements.

3. International verification needs.

Physical Security, Materials Control and Accountability, IAEA Safeguards, and Physical Security System Facilities are described in Sections 2.3.1 through 2.3.4. These are generally consistent with protecting DOE-defined Category I and II type special nuclear materials. More quantitative and more detailed aspects of S&S needs/requirements will be determined by a site-specific vulnerability threat assessment (VA) and against standards yet to be defined for the variety of material forms that can be accommodated within the boundary conditions for each borehole disposal variant. In Section 2.3.5, we provide comments about the direct disposal of Pu/PuO_2 in compound canisters and discuss selected issues relating to material protection and proliferation resistance prior to disposal of this form.

2.3.1 Physical Security Requirements

Programmatic activities shall be conducted within security areas designated as Property Protection Areas (PPA), Limited Areas (LA), and Protected Areas (PA). A site plan noting these areas is shown in Figure 3.1.7-1.

Entry portals, manned by protective service personnel, provide access to the site. Metal and explosives detectors, badge readers, and other personnel identification devices shall be utilized at appropriate access points to prevent intrusion of unauthorized personnel or the introduction of prohibited articles. The emergency exits may contain physical barriers with access controls utilizing nuclear material detectors and metal detectors to indicate the removal of sensitive material. However, plutonium alarm thresholds will be set at levels consistent with the attractiveness of the material and within other physical parameters that are realistic for each emergency egress portal. In no case should an emergency exit be inhibited or prevented by a positive alarm condition.

Special provisions shall be made in the storage and special-processing areas to protect against internal and external threats. The design/operation of physical security systems and procedures is expected to mitigate or prevent radiological and toxicological sabotage events and to provide a credible basis on which material accountability operations can be carried out.

2.3.1.1 Property Protection Areas (PPA)

The perimeter of the property protection area consists of a physical barrier consistent with site-specific requirements (topography, natural physical barriers, geographic isolation, etc.). The buffer zone preceding the PPA must be provided with sufficient illumination for reasonable observation during hours of normal darkness and under reasonable but otherwise adverse weather conditions. Intrusion detection and assessment should be performed at the protected area perimeter. Entry of private motor vehicles into protected areas should be minimized and limited to authorized parking areas. Access controls would likely be accomplished by a staffed vehicle portal, but this could be optional because access control could be accomplished at individual buildings within the PPA.

2.3.1.2 Limited Areas (LA)

Limited areas are secured with physical barriers consistent with site-specific requirements. Category III and IV materials can be stored or handled in LAs (DOE Order 5633.3A). Access to these areas and to the material stored or handled therein should be limited to persons whose trustworthiness has been predetermined and to persons in their escort. General access to these areas should be kept to the minimum necessary to accomplish the tasks appropriate for such areas. All persons and packages entering/leaving LAs are subject to search and seizure at the discretion of the observing protective security officer. These measures inhibit the introduction of articles of sabotage or the unauthorized removal of nuclear material. Appropriate portable instrumentation should be provided to assist with routine monitoring of personnel entering/exiting LA. Private motor vehicles should be prohibited from access to LAs. The LA is arranged with minimal exit/entry points consistent with safe and efficient operations in the area and is fitted with auxiliary alarmed exits for emergency egress.

2.3.1.3 Protected Areas (PA)

Protected areas are secured with physical barriers consistent with site-specific requirements. Category I and II materials can be stored or handled only in PAs (DOE Order 5633.3A). Access to these areas and to the material stored or handled therein should be limited to persons whose trustworthiness has been predetermined and to persons in their escort. General access to these areas should be kept to the minimum necessary to accomplish the tasks appropriate for such areas. All persons and packages entering leaving PAs should be subject to routine search to prevent the introduction of articles of sabotage or the unauthorized removal of nuclear material. Appropriate fixed instrumentation should be provide to assist with routine monitoring of personnel entering/exiting PAs. Private motor vehicles should be prohibited from access to PAs. Whenever persons are present in a PA, those areas should be under constant surveillance. The surveillance can be affected by mutual observation of two or more coworkers (e.g., the “two-man rule”). The PA is arranged with a minimum of exit/entry points but consistent with safe and efficient operations in this area. Exits fitted with alarms are provided about the PA perimeter to allow for safe and rapid egress in the event of an emergency.

2.3.1.4 Storage Areas

Storage areas located in the Surface Processing Facility (see Figure 3.1.7-1) should be of a “strong room” design and construction and should minimally meet DOE Order 5634.1B. They should be provided with alarms and adequate locks. The issuance of keys or key cards should be closely controlled. Access to storage should be strictly limited to assigned persons or to persons under appropriate escort. Where nuclear material is stored overnight in work areas or in sub-storage structures, specially authorized procedures should be used to protect the area. Alarms, patrols, and TV surveillance monitors can be used to help satisfy this requirement. Nearby areas shall provide space, shielding, and access for weighing, gamma fingerprinting (measurement), verification of bar codes for the primary containers, and verification of empty storage locations.

2.3.1.5 Access Control

All persons entering a PA should be issued special passes or appropriated registered badges. Badging of persons entering LAs or PAs should follow graded procedures noted below:

Type I: An employee whose duty permits or requires continual access to the area.

Type II: Other employees who are otherwise permitted access to the area.

Type III: Temporary personnel with appropriate business in the area and escorted by employees with Type I or Type II badges as appropriate.

Type IV: Visitors and other guests escorted by employees with Type I or Type II badges as appropriate.

Passes and badges should be designed to prevent counterfeiting.

2.3.1.6 Key Control

Records must be kept of all persons having access to or possession of keys or key cards that access the containment or storage of nuclear material. Arrangements should be made to minimize the possibility of key duplication, and combinations should be changed at suitable intervals.

2.3.1.7 Communications

Independent redundant transmission systems for two-way voice communication should be provided for activities involving intrusion detection, assessment, and response. This should include links between guards, their headquarters, and the respective response forces. Independent, redundant transmission systems, including independent power supplies, should be provided between sensors and alarm display (audible and/or visual) areas.

2.3.1.8 Protective Forces

A 24-hr armed guarding service must be provided to carry out routine internal and external patrols. The guards should report at scheduled intervals to local or other security forces during non-working hours. The overall objective of this force is to prevent the unauthorized removal of nuclear materials. Appropriate backup forces should be identified to assist the active on-site force with this task as required.

2.3.1.9 Employee Training

All employees should be annually informed of the importance of effective physical protection measures and should be trained in their implementation. Notices on the subject should be conspicuously posted throughout the facility.

2.3.1.10 Material Security Transfer

Every nuclear material handler should be required to conform to procedures transferring custody of the nuclear material to a succeeding handler. Handlers are expected to be aware of inventories under their direct control and to be able to quickly identify any discrepancies and potential diversions of nuclear material. Movements of nuclear materials within PAs and LAs should be the responsibility of an appropriately identified supervisor or control authority. All prudent and necessary physical protection measures must be applied to such transfers. Nuclear material movement between two protected areas should be treated in full compliance with the requirements for nuclear material in transit after taking account of appropriate site conditions.

2.3.1.11 Emergency Planning

Emergency plans of action should be prepared to counter effectively any possible threat, including attempted unauthorized removal of nuclear material or facility sabotage. Plans should provide training to facility personnel to act appropriately in case of alarm or emergency. Personnel trained at the facility should be prepared to meet all necessary demands of physical protection and recovery of nuclear material and should act in full coordination with appropriately trained response forces and safety response teams. Arrangements must be made to ensure that nuclear material is not removed in an unauthorized manner during emergency evacuation conditions or drills.

2.3.1.12 Annual Surveys

A security survey should be made annually (or whenever a significant change in the function of the facility is recorded) by an appropriately designated physical protection authority to evaluate the effectiveness of the site's physical protection measures and to identify necessary changes in measures that would optimize the Safeguards and Security Plan of the site.

2.3.2 Physical Security System Facilities

2.3.2.1 Site Fencing

The Site Map given in Figure 3.1.7-1 shows security boundaries: the Protected Areas (PAs), Limited Areas (LAs), and the Property Protection Areas (PPAs). Operations involving the plutonium disposal form in the Surface Processing Facility must be performed in a Material Access Area (MAA) that is hardened for security purposes. The MAA and facilities supporting MAA operations are located in a PA. The Emplacement–Borehole Sealing Facility to which the emplacement canisters are brought is also within a PA. Each PA is secured with a double fence and intruder detection systems. The PA and operations involving classified materials are contained within the LA. The PPA surrounds the LA and includes the buffer zone around the facility. The passenger vehicle parking and personnel services (e.g., cafeteria and training center) facilities are located outside the LA but within the PPA.

2.3.2.2 Security Processing—Employees/ Visitors Center

Security Processing—Employees/Visitors Center will serve as the initial point of entry for plant visitors. Functions performed in this area include badge and pass, security office, file room, visitor control room, and visitor orientation rooms. Space is provided for badging and dosimeter distribution for plant employees. This facility will be located in the Personnel Services building, within the PPA.

2.3.2.3 Security Center

The Security Center serves as the security administrative headquarters and contains a pistol firing range, an armory, lockers, change rooms, training and meeting rooms, offices, and a storage room for supplies.

2.3.2.4 Personnel and Vehicle Access Control

Regular access to the PPA of the facility by pedestrians and vehicles will be through the west gate, where a guardhouse and access control facility is located. Visitors will be routed to the Security Processing—Employees/ Visitors Center for clearance, badging, and/or escort. Access to the LA of the facility will be through the west gate at the LA perimeter. Additional manned access-control booths are provided for pedestrian and vehicular traffic to the PAs.

Rail and truck access to the facility will be through the east gate at the combined perimeter of the PPA and the LA at that location. A guardhouse and an access control facility are provided at this entrance. As shown in the Site Plan, the entire borehole array area is located within the LA, while the Emplacing–Borehole Sealing Facility is provided the additional security of a PA fence, a guardhouse, and an appropriate access-control facility for pedestrians and vehicular traffic.

2.3.2.5 Security Monitoring and Intrusion Alarm Systems

The Security Center will contain the Access Control and Monitoring Center for safeguarding the main facility area and the borehole array area. This facility will be manned 24 hours per day. The features provided for physical protection of the site include site fencing, intruder detection devices, site lighting and closed circuit remote viewing systems, communications systems, personal access/ egress control systems, guardhouses, and vehicle control stations (rail, truck, and passenger vehicles). The PA and LA fences will be lighted at night and will be protected by intruder alarm systems and remote surveillance capabilities 24 hours per day.

2.3.2.6 Computer Security

The facility will develop an overall computer security plan so that hardware, software, and database integrity are protected against site-specific threats. This plan will include protection of computer-related activities for physical protection and for material control and accountability.

2.3.3 Material Control and Accountability

It is expected that the amount of nuclear material transported to the site, minus any amount held captive in waste-stream residues from processing activities, will equal the amount of material deposited in the site's borehole. An integrated site material balance system must be set in place to ensure that this balance is accomplished and available for verification. Measurement systems for the determination of nuclear materials received, diverted through waste streams, or otherwise disposed of must be provided as an integral component of the material accounting activity. These systems will be periodically evaluated for precision and accuracy and for the estimation of measurement uncertainty. Material Balance and Accountability (MC&A) combines elements of Waste Monitoring, Material Control and Accountability Measurements, Nuclear Material Control, and Material Accountability as outlined below.

2.3.3.1 Material Accountability

The accountability portion of the Safeguards system provides timely information for the location and amount of all nuclear materials in the facility and is designed to detect abrupt or protracted (multiple) thefts/diversions. The Accountability System provides a means of physically accounting for the disposition of nuclear material and is supported by established measurement control methods and procedures. New technologies and automated techniques will be implemented where practical to reduce requirements for employee access to accountable nuclear materials and to reduce employee exposure to hazardous environments.

The Deep Borehole Disposal Facility will be subdivided into Material Balance Areas (MBAs) for plutonium control and accounting. This covers both the Surface Processing and Emplacing–Borehole Sealing Facilities.

The Receiving, Processing, and Process Waste Management Buildings together form a Material Balance Area (MBA). The plutonium receiving area will satisfy all physical security requirements as described in DOE Order 5632.1C and DOE M5632.1C-1. When disposal form is classified because of configuration/content, etc., it shall receive the physical protection required by the highest level of classification appropriate for its potential military application.

The amount of nuclear material entering this MBA complex is determined by shipping records and may be validated by direct measurement. Radioactive waste residues, which are the result of processing activities, are removed from Receiving and Processing Building and may be placed in limited storage for less than 90 days from the time of their generation. During this period, waste containers must be assayed for nuclear material and monitored for surface contamination before they leave the Waste Handling Area. The plutonium will be prevented from leaving the MBA until satisfactory material balance is ensured or unless other factors can reasonably guarantee that the waste contains no accountable nuclear material.

2.3.3.2 Nuclear Material Control

The material control portion of the Safeguards System governs internal transfer (or movement), location, access, and use of nuclear material; it also monitors the status of process flows and inventories. The Material Control System is closely associated with, and (as needed) uses data from, the Site Process Control, Surface Criticality Safety, ES&H, and Access Control systems to detect abnormal situations involving nuclear material and/or MC&A system components.

2.3.3.3 MC&A System Integration

This system monitors the storage, processing, and transfer of nuclear materials to detect non-normal events so that no nuclear materials are inadvertently lost, no unauthorized removals occur, and nuclear materials are accounted for and adequately measured. Exact performance of the MC&A system is driven by required loss detection sensitivities that are capable of detecting losses and localizing inventory balances for anomaly resolution. The nuclear MC&A system ties closely with the physical security system of the facility to provide credible assurance that no theft or diversion of nuclear material has occurred.

2.3.4 IAEA Safeguards Requirements

The objective of IAEA safeguards is the timely detection of the diversion of significant quantities of nuclear materials to activities that have military applications. Material accountancy is used together with containment and surveillance as complementary safeguards techniques. A system of accounting for the control of all nuclear materials will be based on a structure of MBAs.

2.3.4.1 General Accountability

To satisfy IAEA verification requirements, the site must establish acceptable procedures for identifying, reviewing, and evaluating differences in shipper–receiver measurements, for taking acceptable physical inventories, and for evaluating accumulations of unmeasured inventory and unmeasured losses. The site must also establish an acceptable system of records showing, for each MBA, receipts for changes involving transfers into and out of such areas. Provisions must also be made to ensure that accounting procedures and other arrangements are operated correctly. All of these feature should be accommodated by the general Materials Balance and Accounting activities described in Section 2.3.2.

2.3.4.2 Records Systems

Borehole site records shall be retained for at least 5 yr, but facility post-closure security and safeguarding requirements may dictate retention of these records for a much longer period. This applies to operating records, accounting records, calibration records, etc.

2.3.4.3 International Inspection Provisions

An International Inspection Area (IIA) is likely to be a required component of the site. An IIA is used by international inspectors for inspection and verification of fissile materials. Prior to facility attachment negotiations with IAEA, this inspection is expected to be limited to primary containment vessel (PCV) identification, gross weight, and gross radiation count. The IIA houses equipment provided by the international agency and contains files necessary to carry out authorized surveillance without allowing access to classified information. Inspection activities also include site visits for reviewing records and information recorded by installed instrumentation and CCTV cameras that belong to the inspecting organization. Equipment located inside the inspection area may be operated by the inspectors remotely through a control room with direct viewing into the inspection area. Special uninterruptable power supply (UPS) and other systems would be provided by international agreements.

2.3.5 Safeguards and Security Requirements Related to Proliferation Resistance of the Direct Pu/PuO_2 Disposal Option

The facility is projected to sustain a disposal rate per year of 5 t of Pu/PuO_2 product with a surge rate of 10 t/yr. On a per day basis, the facility must handle a minimum of 20 kg of plutonium per day and 40 kg per day during surge operation. In addition, the facility requires a 1-month inventory (417 kg) of Pu/PuO_2 material in storage for processing operations. At the Receiving Facility, the material will be received in 6M/2R-like transportation packages each containing two product cans and a total of 4.5 kg of plutonium encapsulated in a special sealant that fills the PCV. Here each 6M package will be opened, inspected, and stored. Subsequently, batches of nine PCVs will be placed and sealed within each 0.41-m-diam (16-in.), 6.1-m-long (20-ft) emplacement canister, each of which will contain 40.5 kg of plutonium. Twenty-five emplacement canisters will be transported in smaller batches to the Emplacing Facility, where they will be threaded together into a single canister string (containing a total of 1012.5 kg of plutonium), which is lowered into the borehole and sealed in place. These figures represent the plutonium flow rates in the areas where handling, interim storage, and disposal operations are carried out.

DOE Orders set rigid guidelines for determining Category I, II, III, and IV materials when plutonium is the attractive element. Each sample category is defined by an "attractiveness level," which grades the material against criteria associated with its material form and/or elemental purity, and a "kilogram quantity level," which is simply a measure of the mass of plutonium present in the sample. The category assigned to a collection of plutonium-laden materials directly determines their security protection level. High-grade plutonium materials, without regard to form, are identified as Category I or II and require the highest level of protection if they exceed an aggregate plutonium mass of 2 kg. From the presentation in the preceding paragraph, these materials and the quantities involved are clearly Category I or Category II materials (DOE Order 5633.3A) and therefore require the highest level of protection.

The issue of protection levels for Pu/PuO_2 direct disposal forms can be considered from another perspective. The term "Spent Fuel Standard" was coined by the National Academy of Sciences (1994) in their study *Management and Disposition of Excess Weapons Plutonium.* In brief, the NAS study suggested that plutonium disposal forms should be "…rendered at least as proliferation resistant as the plutonium existing in commercial spent fuel…" and stated that "…deep boreholes represent a class of options that go a long way towards eliminating the proliferation risks posed by excess weapons plutonium…." A recent interpretation by Rhoads (1995) of this standard succinctly states that the "…form of a material alone does not provide sufficient proliferation resistance." While the NAS study clearly focused on the attributes of the disposal form in the definition of the Spent Fuel Standard, it failed to state clearly that the increased proliferation resistance conferred on a disposition method by physical inaccessibility and the prohibitive cost of retrieval of the disposed material should be included in the Spent Fuel Standard. Because the Pu/PuO_2 direct disposal form is a concentrated non-immobilized form of plutonium, it does not possess any proliferation resistance attributable to the disposal form itself. Clearly, the principal means by which the deep borehole disposal concept satisfies the need for proliferation resistance is through making the material physically inaccessible. Therefore, in applying the Spent Fuel Standard to this Deep Borehole Direct Disposal Alternative, the standard should be more broadly interpreted to include the physical inaccessibility to all except the host country in possession of the site and the high cost of retrieving the disposed material.

The emplacement scheme and the potential aboveground residence time of large quantities of encapsulated plutonium closely replicates conditions of past nuclear device emplacements at the Nevada Test Site. Lengthy historical experience with successful protection and adequate Safeguards and Security controls of these activities suggest confidence that the Pu/PuO_2 direct disposal emplacement activities can be securely executed. In summary, when viewed from the perspectives of both the DOE regulations and the protection standards derived from the NAS study, the Safeguards and Security requirements for this direct disposal option cannot at this time be significantly moderated or relaxed below those stated above.

3. GENERIC SITE DESCRIPTION, SITE MAP AND LAND USE REQUIREMENTS

3.1 GENERIC SITE DESCRIPTION

The Deep Borehole Disposal Facility site described here is a generic site at a *hypothetical* geographical location in the United States called Deep Rock. In developing this generic site description, the characteristics of an ideal site have been used for guidance to arrive at a realistic description of a site that can be found in a number of areas in the continental United States. Site information is provided at a level of detail sufficient to make an approximate assessment of the environmental impact at the site. The data provided includes the geographical and topographical features of the area, the subsurface geology and hydrology, the climate, the levels of seismic activity and wind speeds, the population densities and population centers, rail, road, and air traffic accessways, and a site map.

3.1.1 Geographic Setting

The Deep Rock site, shown in Figure 3.1.1-1, is located in a rural area surrounded by farmland and characterized by low, rolling terrain. The average elevation is 200 m above sea level. The topography of the area is rather flat with a maximum topographic relief of 25 m over the 20 km × 20 km area shown in Figure 3.1.1-1. The Deep Rock River is a medium size river (8 m average depth, 100 m average width) that originates in a drainage basin (1,600 km^2 area) located on a low plateau (20 m high) to the north of the site. Approximately 815 million m^3 of water flows down the river each year, with a three-fold increase in flow rate during spring over that during summer. The river flows off the plateau onto a flat plain and then flows to the southeast, parallel to the northwest–southeast trending bluff at the plateau boundary. About 5 km further downstream, the river flows into the shallow Deep Rock Lake (10 m avg. depth, 1 km wide, 4 km long) and then continues beyond the lake to flow southeast parallel to the bluff.

3.1.2 Climate

The Deep Borehole Disposal Facility site is located in the southwest corner of the area shown in Figure 3.1.1-1. The site is above the 100-yr flood plain of the Deep Rock River, whose level increases during spring by at most 1 m. The climate in the area can be characterized as semi-arid sub-humid. The average winter and summer high temperatures are –8.3°C and 26.7°C, respectively. It is, however, a windy location, with winter blizzards and spring and summer tornadoes and a minimum basic wind speed level of 113–129 km/hr as defined in the Uniform Building Code.

3.1.3 Demographics

The nearest town, Deep Rock, is located 18 km from the site and has a declining population, now numbering about 4,000. The nearest city with a population greater than 50,000 is 60 km northeast of the site. The rural population density is less than 4 persons/km^2. There are no major commercial air-traffic routes within 100 km, and the local instrument lanes for air traffic are 30 km away. Minor oil and gas pipelines are located 50 km from the site.

3.1.4 Natural Resources and Land Use

There are no known mineral resources, ongoing mining/resource extraction activities, or protected lands (parks, Indian lands, national forests) within 50 km of the site. The principal economic activity in the area is alfalfa, wheat, and sorghum farming, concentrated in a narrow 1-km-wide strip along the southwestern bank of the Deep Rock River and the Deep Rock Lake, and cattle and sheep ranching extending over a wider area. Water for use by the residents of the town of Deep Rock is obtained from Deep Rock Lake. Although the farmers and ranchers rely primarily on surface water pumped from the river and the lake, ranchers occasionally rely on well water for their livestock. The well water is pumped to the surface from an aquifer in the fractured siltstone and sandstone formation that underlies this area (see Section 3.1.5, below). The nearest water well, about 5 km from the Deep Rock Site, is a 150-m-deep livestock watering well that is pumped 24 hr/day at a maximum rate of about 38 L/min (10 gal/min).

3.1.5 Subsurface Geology and Hydrology

The geology of the area consists of Precambrian crystalline rocks (Zones 3 and 4 in Figure 3.1.5-1) overlain by 250 m of well-cemented, interbedded Cambrian siltstone and sandstone (Zone 2). The Precambrian rock outcrops about 38 km from the site in a wilderness area. The siltstone and sandstone is overlain by a thin clayey-silt soil cover (Zone 1) of 10 m average thickness and 20 m maximum thickness. The siltstones and sandstones in Zone 2 have a well-developed fracture pattern with horizontal and vertical joint orientations and anisotropic permeability.

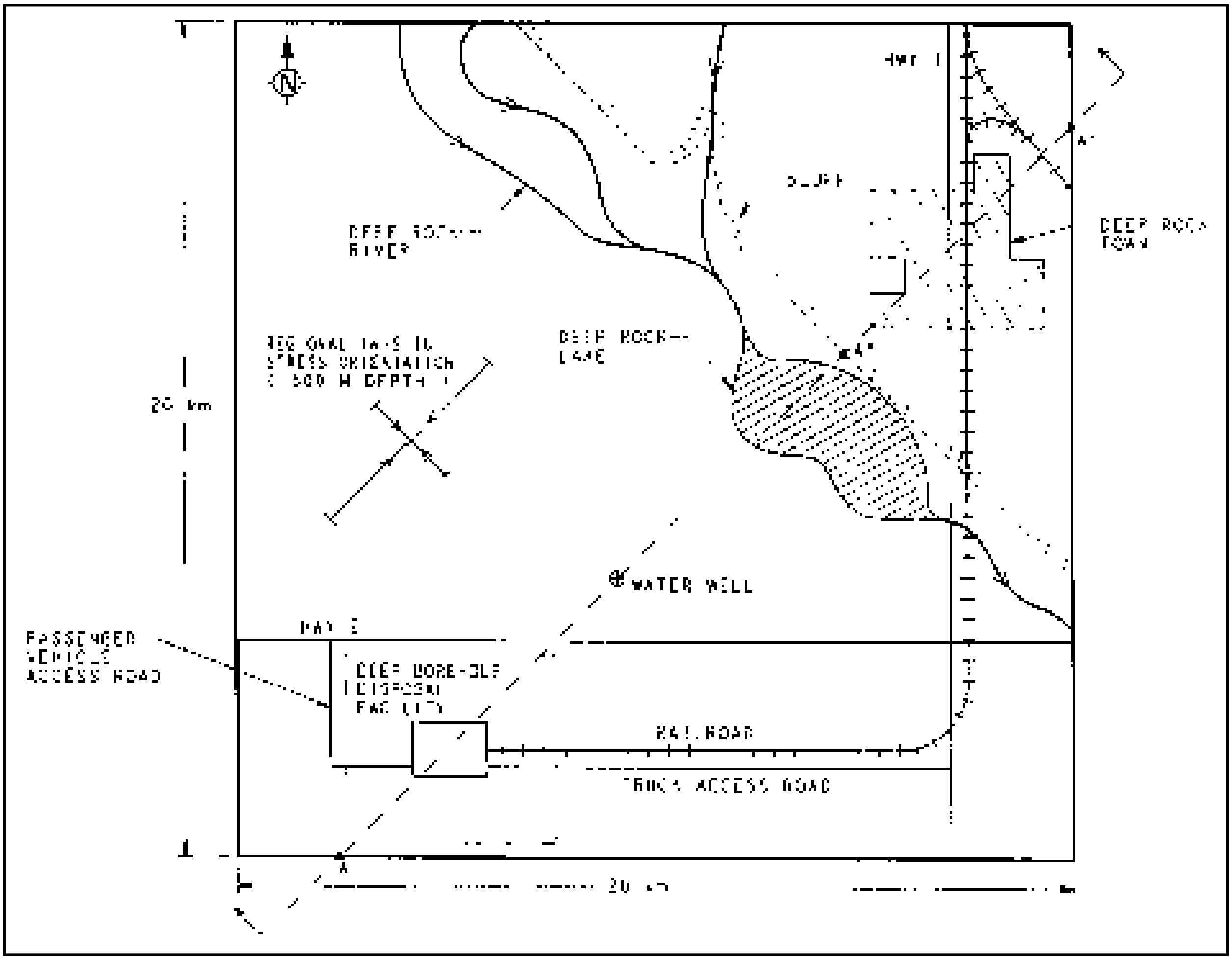

Figure 3.1.1-1. Geographic Generic Site Area Map of Deep Borehole Disposal Facility.

Zone 3 is a moderately fractured granite with subvertical joints extending downwards from the Zone 2/Zone 3 boundary to a depth of 250 m. The deep crystalline rock in Zone 4, extending below 1,000 m, is a sparsely fractured granite of very low permeability.

The primary pathways for deep groundwater flow in the area are the Fault Zone Sets 1, 2, and 3 located in the crystalline rock Zones 3 and 4. The slightly dipping (1 in 5 slope) sub-horizontal thrust Fault Zones in Sets 2 and 3 terminate against the steeply dipping (10 in 1 slope) subvertical normal Fault Zones in Set 1. The fault zones belonging to the subvertical Fault Zone Set 1 are 20 m thick and persist to a depth of about 5,000 m with decreasing permeability. Fault Zones in Set 2 are 20 m thick; those in Set 3 are 5 m thick. The sub-horizontal fault zones, and to a lesser extent the subvertical fault zones, are connected to the joints in Zone 2 and the subvertical joints in Zone 3. The hydraulic and transport properties of these hydrogeologic zones are given in Table 3.1.5-1.

The water table is rather shallow, ranging in depth from 1 m in low-lying areas to 5 m in topographically high areas. Consequently, the water table closely follows the surface topography of the area. Infiltration and percolation of rain and snowmelt recharges the groundwater flow systems in the soil from the topographic highs. The water table reaches the annual maximum levels when the spring snowmelts are supplemented by rainfall. Water levels recede during the summer because of moisture loss by evapotranspiration. Typically, water table fluctuations are small (less than 1 m) and, after normal water table levels are reached, most of the rainfall runs off to surface streams that in turn flow into the Deep Rock River and Deep Rock Lake. It is estimated that only 2% of the total snowmelt [18 cm (7 in.)] plus rainfall [33 cm (13 in.)], for an equiva-

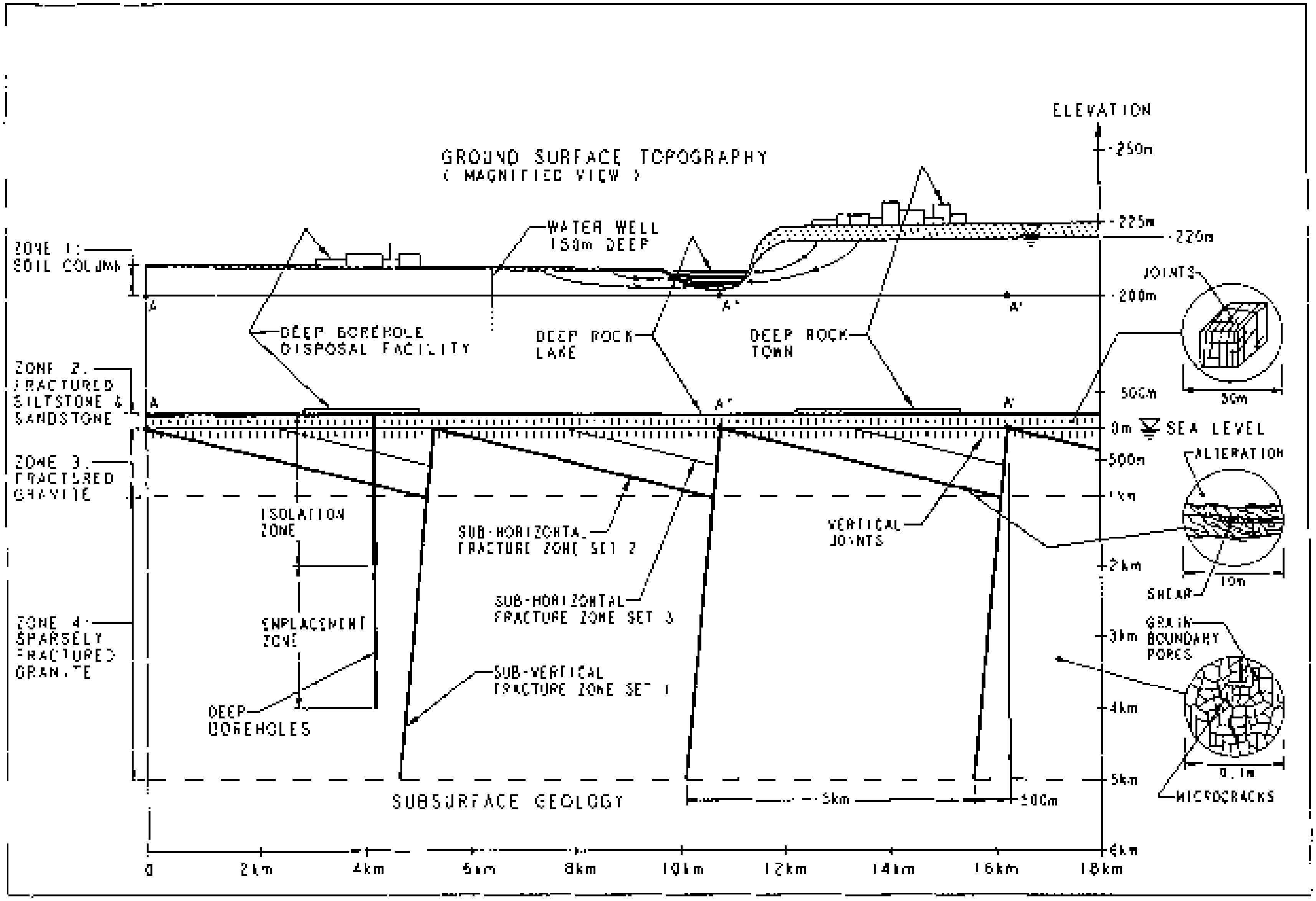

Figure 3.1.5-1. Geologic Cross Section on A–A´ (Figure 3.1.1-1) of Hydrogeologic Features at the Deep Borehole Disposal Facility.

Table 3.1.5-1. Hydraulic and Transport Properties of the Geohydrologic Zones.

Hydrogeologic Zone	Depth Range (m)	Thickness (m)	Porosity (fraction)	Horizontal/ Longitudinal Permeability (m^2)	Vertical/ Lateral Permeability (m^2)	Partition Coefficient K_d (mL/g)	Retardation Factor R for Pu[(1)]	Salinity (g/L)
Zone 1: Soil cover	–275 to –250	25	3.0×10^{-1}	1.0×10^{-13}	5.0×10^{-13}	301	1,200	0.1
Zone 2: Fractured siltstone, sandstone	–250 to 0	250	5.0×10^{-2}	1.0×10^{-15}	5.0×10^{-15}	146	31,900	0.5
Zone 3: Moderately fractured granite	0 to 250	250	1.0×10^{-2}	1.0×10^{-17}	5.0×10^{-15}	10.5	2,900	10
Zone 3: Moderately fractured granite	250 to 1,000	750	5.0×10^{-3}	1.0×10^{-17}	1.0×10^{-16}	10.5	5,840	10
Zone 4: Sparsely fractured granite	1,000 to 2,000	1,000	3.0×10^{-3}	1.0×10^{-21}	1.0×10^{-21}	3.02	2,810	50
Zone 4: Sparsely fractured granite	2,000 to 3,000	1,000	2.0×10^{-3}	1.0×10^{-22}	1.0×10^{-22}	1.78	2,490	100
Zone 4: Sparsely fractured granite	3,000 to 5,000	2,000	1.0×10^{-3}	1.0×10^{-23}	1.0×10^{-23}	1.31	3,660	150
Zone 4: Sparsely fractured granite	5,000 to 8,000	3,000	1.0×10^{-4}	1.0×10^{-24}	1.0×10^{-24}	0.78	21,700	300
Fault Zone Set 1	0 to 1,000	20	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10
Fault Zone Set 1	1,000 to 2,000	20	4.0×10^{-2}	5.0×10^{-14}	2.5×10^{-14}	8.17	432	50
Fault Zone Set 1	2,000 to 3,000	20	3.0×10^{-2}	1.0×10^{-14}	5.0×10^{-15}	5.83	415	100
Fault Zone Set 1	3,000 to 5,000	20	2.0×10^{-2}	5.0×10^{-15}	2.5×10^{-15}	4.90	529	150
Fault Zone Set 2	0 to 1,000	20	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10
Fault Zone Set 3	0 to 500	5	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10

[(1)] Retardation factor (dimensionless) is defined by $R = 1 + [(1 - \phi)/\phi]\rho K_d$, where ϕ is the porosity, ρ is the solid density (g/mL), and K_d is the partition coeffient (mL/g).

lent of 51 cm (20 in.) precipitation per year, reaches the water table. The small amount of water that does reach the water table by direct infiltration through the soil flows along the soil cover in Zone 1 and, to a lesser extent, through the fractured siltstones and sandstones in Zone 2 to the Deep Rock River.

The deep groundwater system is hydraulically connected to the fractured Zone 2, primarily through the subvertical joints in Zone 3. Any surface recharge into the deep groundwater flow system must therefore occur through water infiltrating downwards from the Deep Rock River through the joints in Zones 2 and 3 to the faults in Fault Zone Sets 2 and 3 and (to a lesser extent) in Fault Zone Set 1. However, because the low topographic relief at the surface provides minimal hydraulic potential difference for driving fluid flows, and because the permeabilities of the rock in Zone 4 and the fractures in Fault Zone Set 1 below 2 km depth are very low, it is unlikely that the deep groundwater flow is significantly affected by surface recharge.

3.1.6 Seismicity and Geologic Stability

It is known that the region in which Deep Rock site is located is extremely stable tectonically with no recorded earthquakes with a Mercalli intensity above V. The site falls in the 0–1 seismic zone category range, as defined in the Uniform Building Code, corresponding to seismic accelerations of less than 0.075 *g*. The region has no recorded volcanic or geothermal activity, and exploratory drilling for resource delineation and scientific purposes has established that the underlying crystalline rock has remained undisturbed for hundreds of millions of years. The geothermal gradient in this rock is moderate and relatively uniform at 15°C/km. The salinity gradient, however, exhibits significant variation on shorter spatial scales superimposed on an increasing average trend with increasing depth. For example, as indicated in Table 3.1.5-1, the average salinity gradient at the site increases from 1% per km at 0–1 km depth, to 4% per km at 1–2 km depth, to 6% per km at 2–3 km depth; the salinity appears to reach a maximum of about 350 g/L beyond 8 km depth. Dating studies performed on the brines below 1.5 km depth indicate that they are likely to be the original connate waters trapped in the rock at the time the crystalline rock masses were first formed.

3.1.7 Site Map

The Site Map of the Deep Borehole Disposal Facility is given in Figure 3.1.7-1. The map shows the Security Boundaries and Buffer Zone surrounding the facility. It also shows the four boreholes required by this deep borehole direct/disposal facility design and the spacing between the boreholes in the array. Detailed descriptions of the facilities are given in Section 2.1.3. Figure 2.1.2-2 shows in more detail the layout of the facility in the Main Facility and Borehole Array areas. It also shows the access routes for off-site transportation and the two on-site transportation routes for trucks bearing the disposal form.

3.2 Land Area Requirements during Operation

The land areas required to accommodate the footprints of the Deep Borehole Disposal Facility is listed in Table 2.1.3-1, Facilities Data. The facility requires approximately 2,041 hectares (5,044 acres) of land for the entire facility and its 1.6-km-wide (1-mile) Buffer Zone. Of this area, 32 hectares (78 acres) is occupied by the Main Facility, 25 hectares (62 acres) by the Borehole Array, and 1,873 hectares (4,628 acres) by the Buffer Zone. The total land area disturbed during the operation period is approximately 56 hectares (139 acres).

During the Closure period, the main facility area of the Deep Borehole Disposal Facility will be restored and returned to natural conditions. The facility requires the same land area during closure activities as during operation.

During the Post-Closure period, the 25-hectare (62-acre) Borehole Array area will be declared a limited access area indefinitely, and a 1.6-km (1-mile) Buffer Zone of 1,358 hectares (3,355 acres) may also be declared off limits. Thus, the Borehole Array area will require approximately 1,383 hectares (3,417 acres) to be declared off limits. The total disturbed land area will be the approximately 0.1 hectare (0.25 acre) occupied by the 15 m × 15 m (50 ft × 50 ft) concrete security and anti-water infiltration caps installed above the four boreholes.

3.3 Land Area Requirements during Construction

3.3.1 Land Use

The Deep Borehole Disposal Facility requires approximately 4 hectares (10 acres) of land for construction laydown and warehousing and 2 hectares (5 acres) for construction parking.

3.3.2 Off-Site Transportation

At least 1.6 km (1 mile) of two-lane paved road and railroad spur track will have to be constructed to the Deep Borehole Disposal Facility site for worker transportation and for material and equipment delivery. The length of the road connections depends on the specific site.

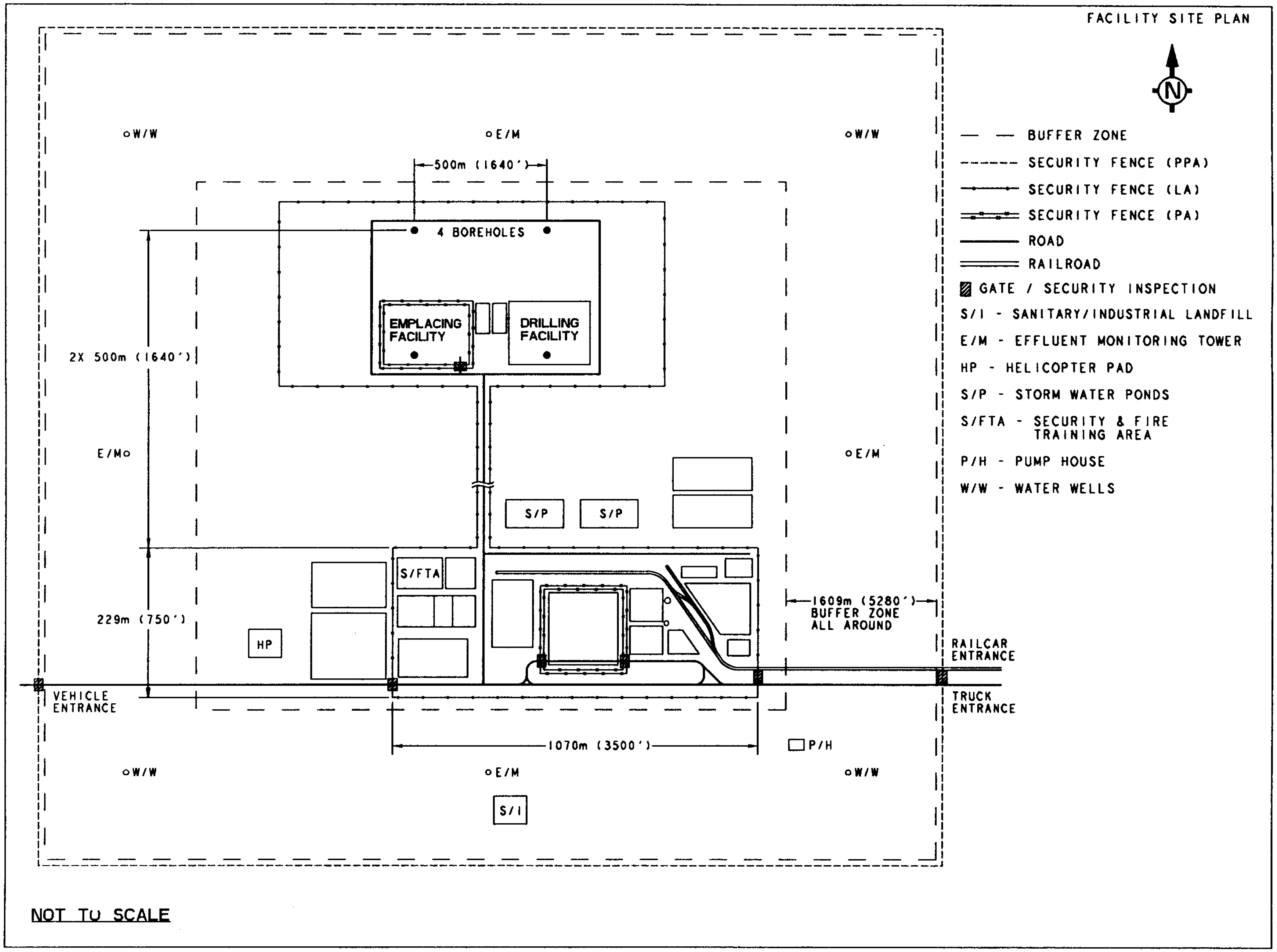

Figure 3.1.7-1. Deep Borehole Disposal Facility Site Map (Including Security Boundaries).

4. PROCESS DESCRIPTIONS

The Deep Borehole Disposal Facility accepts plutonium as plutonium metal and plutonium dioxide disposal forms. Other options, such as plutonium immobilized in glass or ceramic, exist, but only the direct disposal of Pu/PuO_2 disposal forms is considered in this document. The disposal form is emplaced in deep, competent rock with ancient, nearly dormant brine. It is sealed in place to minimize brine intrusion and to prevent criticality. The disposal form is received, placed in large canisters, and stored at the surface processing facility pending transportation on-site to the emplacement facility. Deep boreholes are drilled to a depth of about 4 km and partially cased. The emplacement and sealing facility is located near the boreholes to receive the canister strings, emplace them to depth, and seal them in place.

4.1 SURFACE PROCESSING FACILITY

4.1.1 Function

The process flow diagram and the waste treatment process flow diagram for the Surface Processing Facility are shown in Figure 4.1.1-1. (The overall facility flow diagram is shown in Figure 2.1.1-1.) The Pu/PuO_2 disposal form is delivered in transportation casks to the Surface Processing Facility in PCVs processed at an off-site facility. In the Surface Processing Facility, these "transportation" canisters are unloaded from the transportation casks, inspected, and, if damaged, are overpacked and returned to the facility. The undamaged transportation canisters [approximately 0.14 m diam × 0.51 m high (5.5 in. × 20 in.)] are assembled into larger units by placing them within an emplacement canister [0.41 m diam × 6.1 m high × 1.27 cm wall thickness (16 in. × 20 ft × 0.5 in.)], encapsulating them in place with an appropriate sealant by vacuum impregnation, and using a mechanical seal for the top closure plate. The assembled emplacement canisters are then inspected and stored until they are transported to the emplacement facility. At the emplacement facility, these emplacement canisters are threaded together to form a 152-km-long (500-ft) canister string, the spaces between the individual emplacement canisters are filled with sealant, and the canister string is lowered into the borehole and emplaced as a single unit. The canister string fabrication, emplacement, and sealing procedures are described in Section 4.3.1.

4.1.2 Feeds

The final disposal form of plutonium includes excess PuO_2 or plutonium metal from production or recovery facilities, which is assumed to arrive in 6M/2R-like shipping containers via Safe Secure Trailer (SST) truck. Each PCV holds two plutonium product cans with double containment. Each product can contains approximately 2.25 kg of plutonium. The unloading processing is performed in an airlocked unloading area. Confirmatory and accountability measurements are made after unpacking. Plutonium containers are stored in a shielded storage vault in the transportation canister in which they were delivered before they are placed in the emplacement canister.

The feed rate of Pu/PuO_2 disposal form to the Surface Processing Facility is the equivalent of 5 t/yr of plutonium.

4.1.3 Products

Plutonium containers are removed from storage vault and loaded into a 0.41-m-diam (16-in.), 6.1-m-tall (20-ft) emplacement canister. A crane moves the empty canister to the loading station. After 9 plutonium containers are loaded into the canister and filled with stabilizing material, the canister is moved to the canister welding station, where a lid is welded on to seal the canister. The canister is then moved to the leak test station, where a helium leak test is performed.

The canister is then placed in the canister decontamination station, where its exterior is decontaminated with high-pressure water. The decontamination effluent is transferred to the recycle waste evaporator. After compressed-air drying, the canister is moved to the canister smear test station, its exterior is swiped with paper test swabs to count for radioactivity. If the smearable contamination is below set limits, the clean, sealed canister is transferred to the canister storage area. Otherwise it is recleaned and smear-tested again. The canister is temporarily stored in the facility until it is loaded into a site transporter for transport to the borehole for final emplacement.

Approximately 1,111 transportation canisters and 124 emplacement canisters will be processed annually by the Surface Processing Facility. Each emplacement canister will contain 40.5 kg of plutonium. During surge operation at 10 t/yr of plutonium, these rates will be doubled.

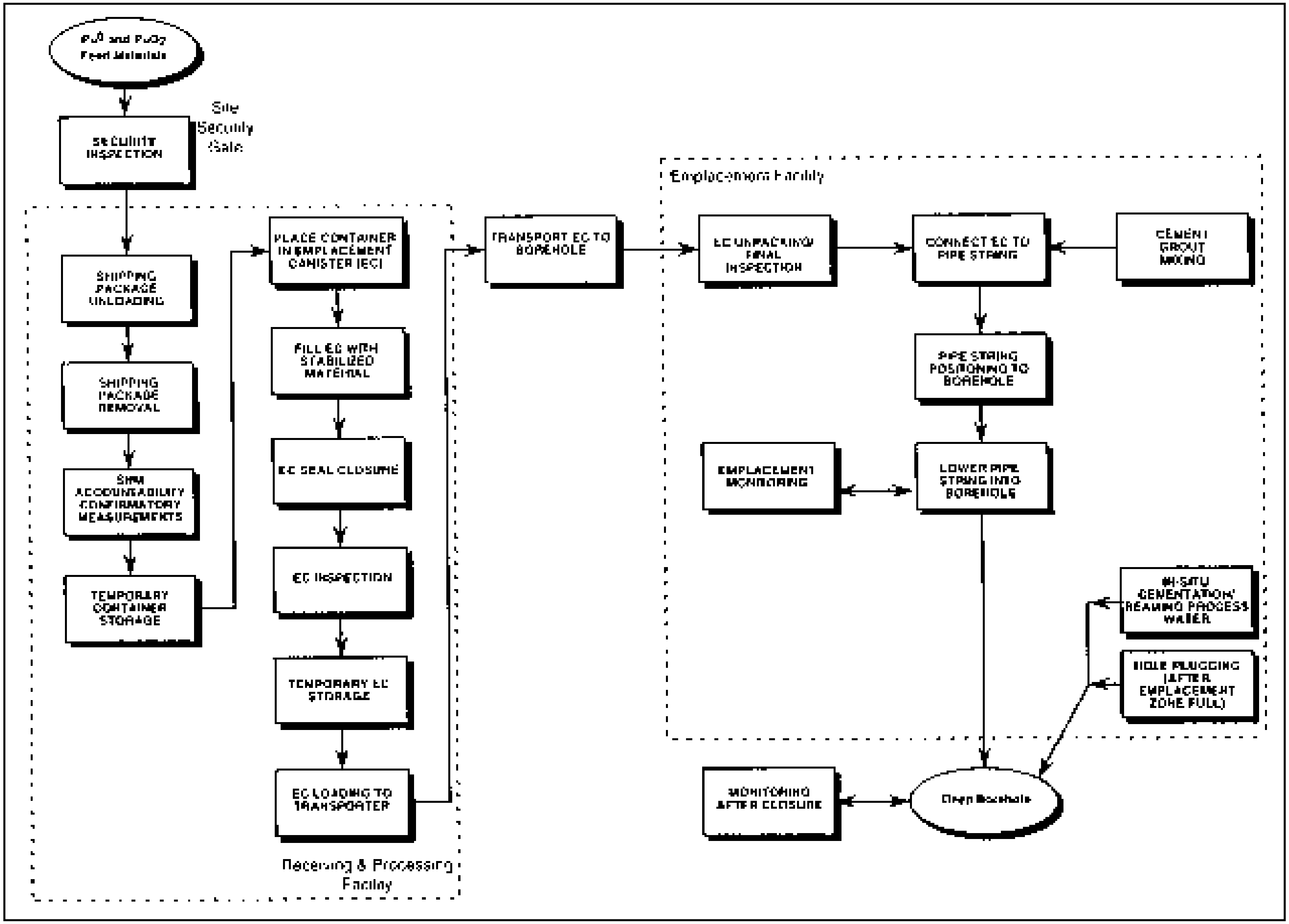

Figure 4.1.1-1. Process Block Flow Diagram.

4.1.4 Utilities Required

The processing at surface facilities requires electrical power, compressed air, and water for utilities functions.

4.1.5 Chemicals Required

The primary process chemicals required for operation of the Surface Processing Facility are those required to prepare the emplacement canister sealant material. A clay-based sealant is used as a solid matrix filler in the emplacement canister to fill the voids inside canister between the plutonium containers and the canister wall to maintain its integrity in the high-pressure environment at the bottom of the borehole. An alternative stabilizing material is bentonite. The final choice will depend on the results of the materials research and development program.

4.1.6 Special Requirements–Support Systems

The process systems required to support the disposition process include cold chemical makeup systems, process gas supply systems, feed and product storage systems, and the material control and accountability system.

- *Storage Vaults*: For plutonium container storage, 3-month storage capacity. For plutonium emplacement canister storage, 6-month storage capacity.
- *Cold Chemical Storage and Makeup System*: For storage of cement, cement additives, etc. Storage capacity of 3 months for storage tanks or silos and 1 day for makeup tanks.
- *Gas Supply System*: For glovebox gas and welding gas supplies, 3-month storage capacity.
- *Material Control and Accountability System*: A material control and accountability system with nondestructive assay and computer systems is required for plutonium material control and accountability (MC&A). The system includes bar code readers, scales, nondestructive assay devices, tamper-indicating item inventory devices, and computers. MC&A is applied to every process transfer point that involves plutonium material. A SNM physical inventory is conducted every 6 months in accordance with DOE Order 5630.2.

4.1.7 Waste Generated

4.1.7.1 Emissions and Effluents

Under normal operating conditions, no radioactivity will be released to the atmosphere during the unpacking of the transportation shipping casks and the repacking into emplacement canisters. If the transportation canisters that are delivered are damaged, small amounts of plutonium-containing dust could escape during unpacking and repacking, and the airborne dust release will be collected by the process area ventilation system. During the vacuum impregnation process, sealant vapor that enters the vacuum system will be filtered out. Air exhaust from plutonium handling and storage areas of the Receiving and Process Facility is discharged to the atmosphere in an exhaust stack after HEPA filtration. The stack release is continuously monitored by an isokinetic air monitoring system.

4.1.7.2 Solid and Liquid Wastes

The wastes generated by the Surface Processing Facility will be sampled for radioactivity and, if free of radiation, will be stored for disposal in an off-site sanitary/industrial disposal facility. If contaminated with radiation, they will be treated as low-level/TRU waste. Solid waste generated from process operations at the surface facilities includes shipping packing materials, deformed plutonium shipping containers, wipes and rags, gloves and paper clothing, and HEPA filters. Liquid waste includes wash water from canister decontamination, spent pump oils, and TCA cleaning solvent. The wastes are sent to the waste handling building for treatment.

4.2 Drilling Facility

4.2.1 Function

The process flow diagram for drilling and the waste treatment process flow diagram for the Drilling Facility are given in Figure 4.2.1-1. The operations involved in drilling are the preparation of the drilling mud with appropriate additives, maintaining the mud column at the proper density, pumping water out when needed to control water inflow from conductive aquifers and fractures, using mud additives and plugging back these features to control the inflows, and installing steel casing and cementing behind the casings as the drilling progresses. The rock cuttings may be left in the mud pits rather than being transported to another location for disposal as may be required by state and local regulations. It is customary to leave the cuttings in the mud pit and to cover the mud pit with soil following completion of the drilling process.

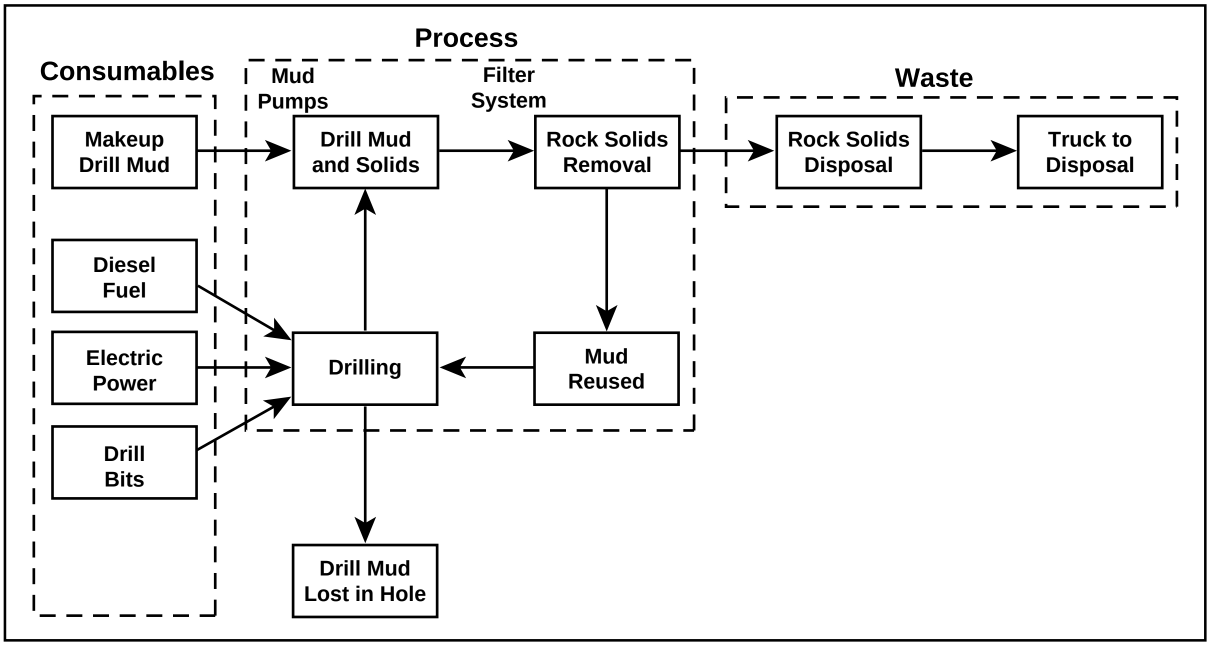

Figure 4.2.1-1. Drilling Process Flow Diagram.

The borehole will be drilled using technology that has been used extensively in the petroleum industry. The drilling system consists of a drill rig (or derrick), which is used to lower and raise the drill pipe and the drill bit in the borehole, and the associated drilling mud and fluids-handling support facilities. A motorized winch called the draw-works provides the lifting power of the derrick. The drill string (a series of connected pipe sections) permits the control of the drill bit itself. A mud mixture containing water, compressed air, and possibly bentonite is pumped into the borehole to bring material drilled from the borehole to the surface. The drilling mud is sent into the mud pits to allow the solids to settle out. The mud is filtered to remove the fine particles and is returned to the pumping system. When drilling holes of large size, it is more appropriate to use what is called dual-string drilling. In this configuration, two drill pipes are used, one inside the other. The drilling fluid flows into the hole through the outer pipe in the annulus, and the cuttings flow up through the center pipe to the top of the borehole. Holes larger than about 0.66 m (26 in.) diameter are generally drilled in this manner to reduce the amount of drilling fluid required.

The most important component in the drill rig is the drill bit, which consists of rolling cones with cutters distributed on their surfaces. The cutters are typically made from hardened steel or tungsten carbide. Diamond bits could also be used. In this case, industrial diamonds are impregnated into the drilling surface of the bit.

Large-diameter boreholes are usually drilled with the borehole diameter decreasing stepwise with depth as shown in Figure 4.2.1-2. The process starts with a relatively large-diameter drill bit, which is used to drill to some desired depth. A metal liner (or casing) with an outside diameter smaller than the borehole is then inserted into the borehole. A cement slurry is then pumped at high pressure into the annulus between the casing and the rock formation. Casing the borehole and cementing behind it serves several purposes. First, it seals the void space between the casing and the borehole wall and eliminates this pathway for convective fluid circulation and transport of mobilized plutonium to the biosphere. Because this is a key factor that would affect the performance of the Deep Borehole Disposal Facility, it is essential that a high-quality cementing job be performed under a strict quality assurance program that uses borehole logging tools for verification. Second, it prevents groundwater from aquifers in the upper portion of the hole from entering and flooding the borehole. Third, at greater depth it will prevent brines from entering the borehole during drilling. Fourth, it prevents collapse of the upper regions of the borehole, where more unstable soils and unconsolidated rocks are usually found. Last, it permits the sealing of fractures in the rock formations that intersect the borehole. The casing and cementing process flow diagram is shown in Figure 4.2.1-3.

At specific locations in the borehole, the hole will be under-reamed (i.e., undercut) to a diameter larger than that of the basic hole. Special cutting tools exist for drilling

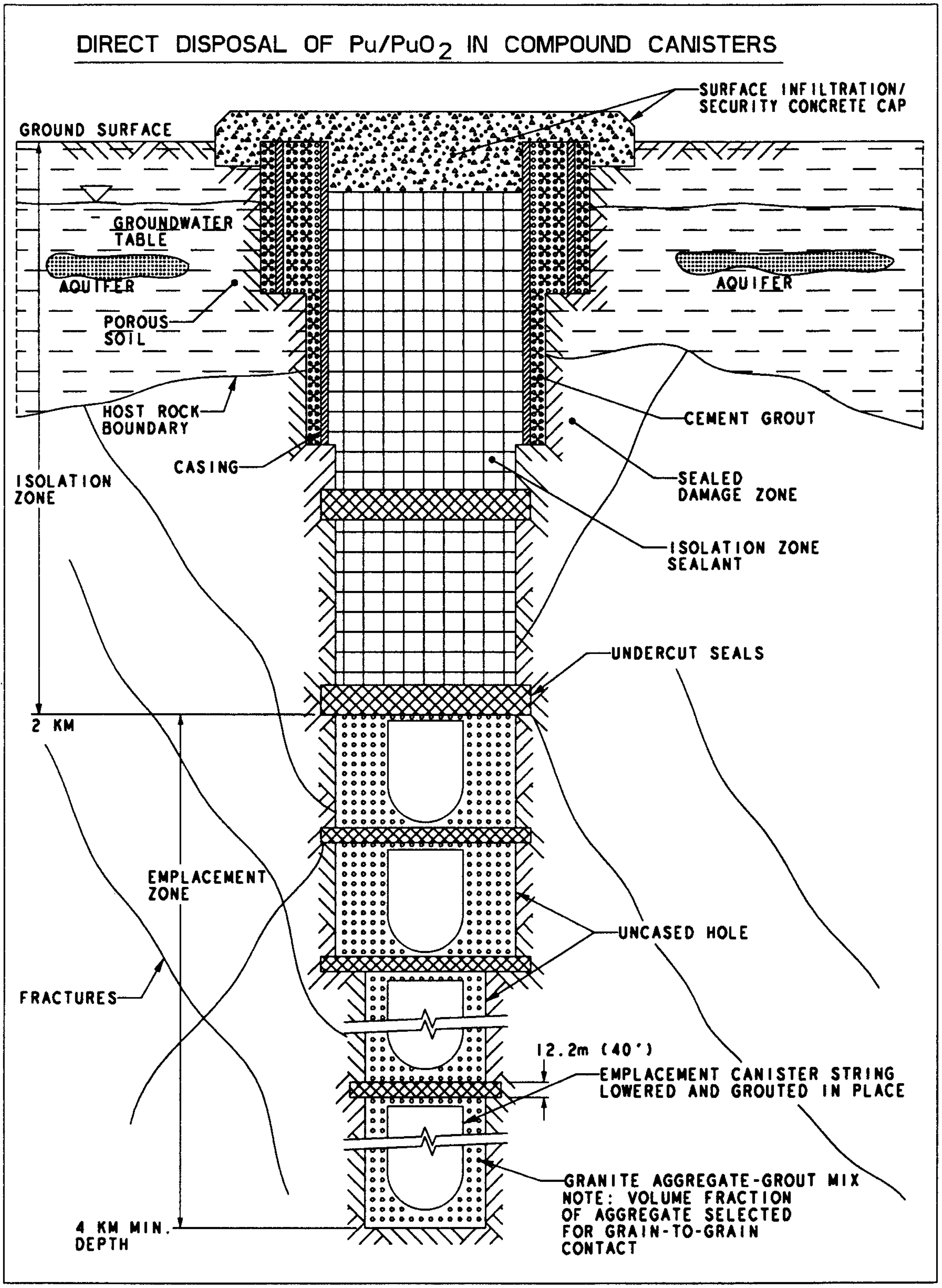

Figure 4.2.1-2. Borehole Configuration Geometry for Direct Disposal of Plutonium Metal/Plutonium Dioxide in Compound Canisters.

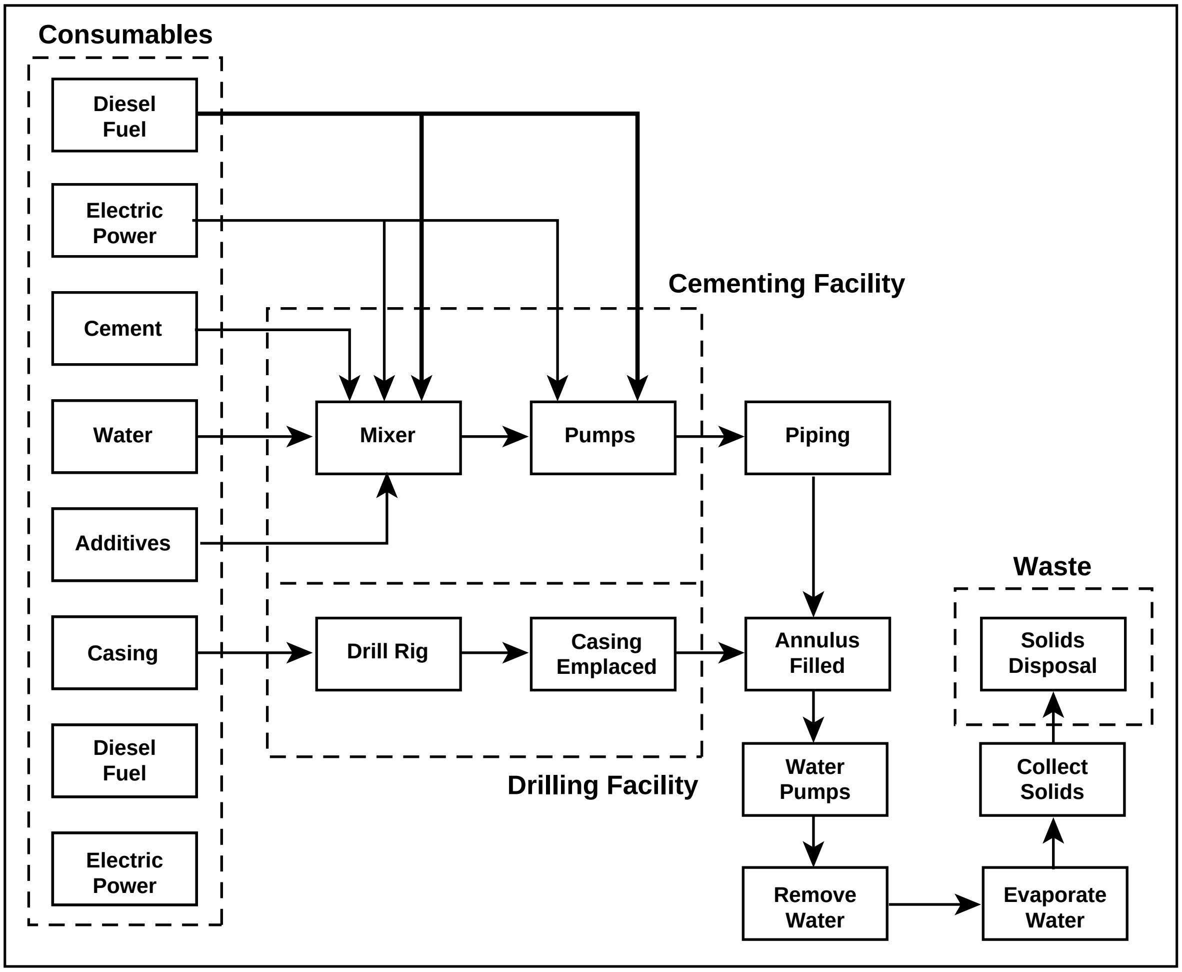

Figure 4.2.1-3. Casing and Cementing Process Flow Diagram.

from the bottom up and increasing the hole diameter to provide a seat for seals and plugs at various depths. The seals and plugs are required to prevent the vertical migration of fluids; they will be installed during canister installation and during borehole closure.

The drilling operation has been examined by drilling experts from Reynolds Electric and Engineering Co., Inc. (REECO) to determine the data required for this report. Their detailed analysis can be found in Russell (1994). REECO estimates that 10 to 11 months will be required to drill a single borehole of the diameter and depth considered here using two 12-hr shifts a day with three rotating drilling crews.

Other borehole size and configuration scenarios might be desirable for this application. For example, depending on the particular geology at the selected site, a larger number of deeper boreholes of smaller diameter may be optimal from the standpoint of drilling efficiency. On the other hand, where the geology permits, shallower boreholes of larger diameter may be optimal from the standpoint of emplacement volumetric efficiency and may reduce the total number of holes required to emplace a given amount of plutonium. However, the feasibility and advantages of these alternatives will depend on their impact on the upstream processes (such as disposal form transportation, processing, and packaging) and must be evaluated from a systems viewpoint.

A substantial development effort to design the drill rigs, handling equipment, and high-strength steel casing programs will be required. The drill rig is most likely to be a scaled-up version of a high-capacity petroleum industry drill rig.

4.2.2 Feeds

Very large quantities of materials such as drilling muds, grouts, casing, and chemical additives will be required for operating the Drilling Facilities. These are described below.

The drilling process requires that the circulating water and drilling muds be periodically replaced by fresh mud, water, and chemicals. The chemicals include polymers, soaps, and pH-control additives.

Plugging conductive aquifer zones and sealing fractures and the near-borehole damage zone requires specially formulated API (American Petroleum Institute)–grade grouts and grout additives as feed materials. The exact composition of the drilling mud cannot be determined until a site has been selected and the geology has been identified to some degree.

Casing the borehole in the upper 2 km isolation zone and cementing behind the casings to plug the voids between the casing and the borehole requires specially formulated grouts and steel casing pipes of various diameters and wall thicknesses.

4.2.3 Products

There are no products in this operation. Wastes generated by the process are identified in Section 4.2.7.

4.2.4 Utilities Required

A diesel generator will provide operating power to each drilling rig. A backup diesel generator is also provided for each drilling rig.

4.2.5 Chemicals Required

The primary process materials required for the drilling process are those required to prepare the drilling mud and to treat the briny overflow water from the mud ponds. No treatment of the small amounts of briny water in the borehole is expected to be required. That water will be contained by the sealing process by in situ solidification of the grout pumped into the borehole and will be incorporated into the cement during its hydration and solidification. Additional grouts are required for sealing the soil and rock formations and cementing behind the casing.

4.2.6 Special Requirements

4.2.6.1 Monitoring for Naturally Occurring Radiation

Drilling operations have a small potential for releasing naturally occurring radiation into the atmosphere, where it might affect workers. Monitoring at the top of the borehole and the bottom of the drill string for alpha, beta, and gamma radiation during drilling operations will therefore be required.

4.2.6.2 Monitoring for Hydrogen Sulfide

A potential exists for hydrogen sulfide to be released from the rock formations during drilling. Appropriate monitoring at the borehole will be required to ensure the safety of the workers.

4.2.7 Waste Generated

4.2.7.1 Emissions and Effluents

Except for engine exhaust fumes and dust, there are no atmospheric emissions in the drilling process. The primary effluents from drilling are the overflow of briny water from the mud ponds and the briny water that would be pumped out from the well from conductive features in the rock. These wastewaters are treated as described in Section 4.2.7.2.

4.2.7.2 Solid and Liquid Wastes

The solid rock cuttings brought out of the borehole by the drilling mud settle out in the drilling mud pit. About 3,339 m^3 (4,367 yd^3) of rock would be removed from a telescoping borehole with a 1.83-m-diam (72-in.) hole drilled to 24.7 m (81 ft), a 1.32-m-diam (52-in.) hole to 2 km (6,560 ft), a 0.91-m-diam (36-in.) hole to 3 km (9,840 ft), and a 0.66-m-diam (26-in.) hole drilled to 4 km (13,120 ft). The cuttings volume, however, would be as much as 1.5 times this volume because of bulking. These cuttings would contain some of the drilling mud additives, and the briny water at depth. The additives will be selected from approved standard stock items in the petroleum industry. The exact makeup of the additives will not be known until the geology of the site has been ascertained. A common drilling practice is to leave the cuttings in the mud pit, which is covered with soil at the completion of drilling operations. Should future or local regulations require other disposal methods, the pits can be lined and the cuttings removed for alternative disposal.

Wastewater generated by the drilling process is tested and then treated as needed by allowing the water to evaporate and burying the residual solids in the mud pits. It is not expected that the water from the drilling mud will require any treatment.

4.3 Emplacing–Borehole Sealing Facility

4.3.1 Function

The process flow diagram for Emplacing–Borehole Sealing and the waste treatment process flow diagram for

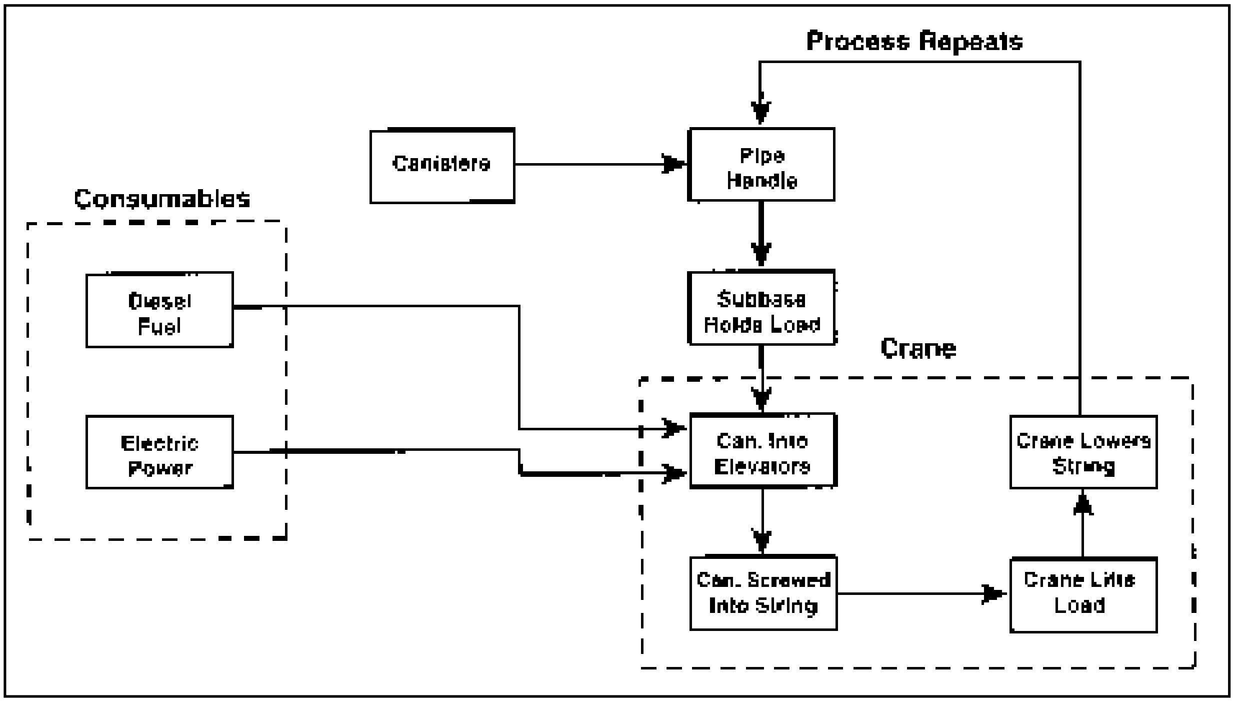

Figure 4.3.1-1. Emplacing Process Flow Diagram.

the facility are given in Figure 4.3.1-1. The assembled emplacement canister modules are transported by truck from the Surface Processing Facility to the emplacement facility. The emplacement facility is located at a borehole that has been drilled and cased after aquifer, fracture, and near-borehole damage zones in the upper 2 km sealing zone have been sealed. A containment structure is provided to cover the entrance to the borehole and the wellhead equipment to contain any plutonium that might be released in the event of an accident during emplacement. The roof of the containment structure will have a sliding seal to accommodate the emplaced canister string. The air inside this structure will be filtered by a two-stage HEPA filter to minimize accident-related airborne releases to the atmosphere. As a part of drilling the borehole, fractures and near-borehole damage zones in the lower 2 km emplacement zone will be sealed. It will be necessary to evaluate in the field the feasibility of sealing these features in the host rock in a large-diameter uncased borehole (using, for example, multiple inflatable packers set at depth and injecting between them).

At the Emplacing–Borehole Sealing Facility, the emplacement canisters that are delivered to the emplacement facility are threaded together just before emplacement to form a single canister string about 152 km (500 ft) long. Each emplacement canister is hoisted off the SST by a crane and is mounted vertically in the emplacing rig. The canister is then threaded to the top of the canister string, which is positioned below in the borehole with its upper end protruding from the borehole. In this way, the canisters are attached one by one to the canister string. Before canister string assembly begins, a plug of specially formulated grout with good hydraulic sealing and chemical durability properties will be installed at the bottom of the borehole above the previously emplaced canister string using a centering jig. This jig may be an annular block of concrete/grout whose central hole is sized to receive the lower end of the next canister string. During the sealing process, it will be encapsulated by the grout and incorporated into the seal. Then the canister string is attached to a drill string and lowered into the borehole. A bullnose at the bottom of the canister string will help avoid snagging of the canister on sharp edges in the borehole. The canister is positioned above the previously installed grout plug. Sealing grout is then pumped in between the canister string and the uncased borehole wall through a pipe until it covers the entire canister string except its very top, where it is held in place by the positioning device. After about 4 hr, when the grout has set sufficiently to hold the canister string in place, the positioning/latching device is detached and raised further up the borehole, and additional grout is pumped in to cover the canister string. Finally, the drill string is withdrawn in preparation for fabricating and emplacing the next canister string. Figure 4.3.1-2 shows the process flow for cementing/sealing. The only

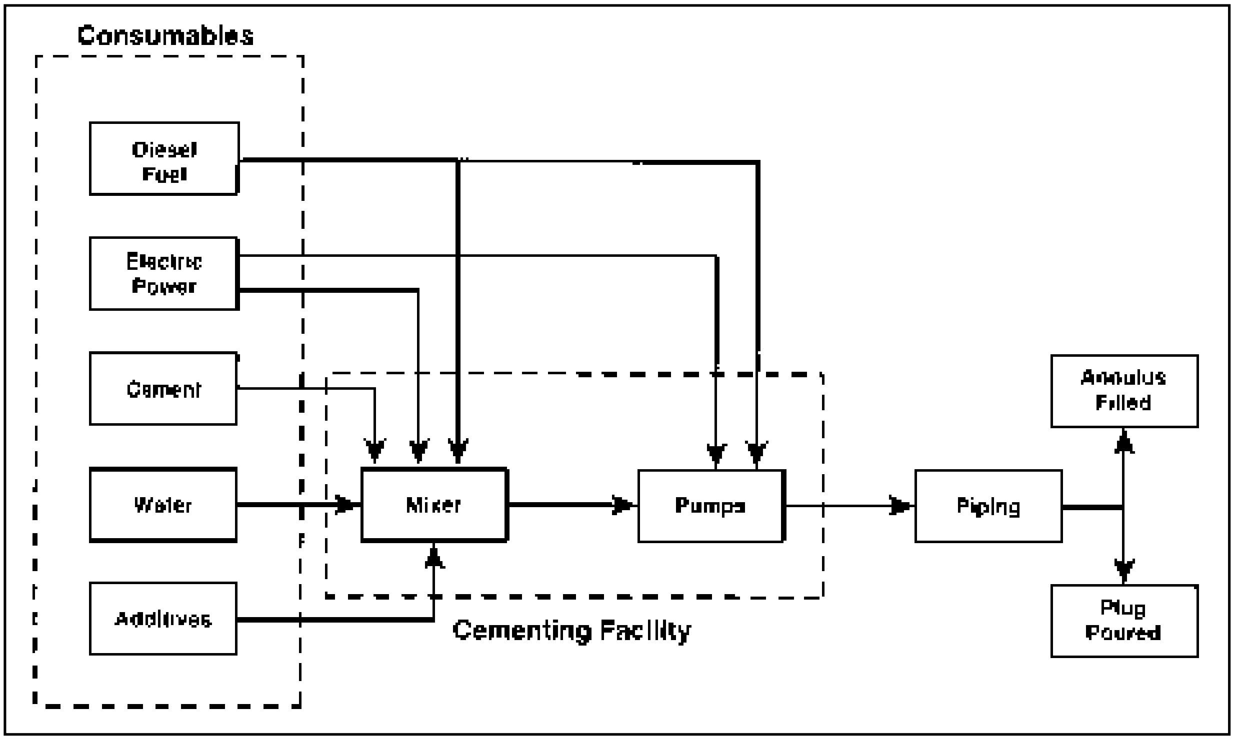

Figure 4.3.1-2. Cementing/Sealing Process Flow Diagram.

difference between the cementing of the canisters and the pumping of the seal plugs is the use of additives in the grout to reduce the hydraulic permeability and contaminant transport through the seals.

Periodically, when one or more canister strings have been emplaced, a hydraulic and transport seal, manufactured from special materials, is installed (see Figure 4.3.1-2) between the canister strings in the borehole. When the entire 2 km emplacement zone is filled in this way, a long hydraulic and transport seal is installed at the top of the Emplacement Zone. Next, the Isolation Zone of the borehole is filled with concrete with periodic hydraulic and transport seals. Finally, a dual-purpose security and anti-water infiltration concrete cap is installed at the entrance to the borehole at ground level.

4.3.2 Feeds

Very large quantities of materials such as grouts, casing, and chemical additives will be required for operating the Emplacing–Borehole Sealing Facilities. These are described below.

The primary feed to the Emplacing–Borehole Sealing Process is the emplacement canisters prepared in the Surface Processing Facility. Approximately 12 canister strings, each containing 25 6.1-km-long (20-ft) emplacement canisters, can be accommodated in one borehole with a 12.2-m (40-ft) hydraulic and transport seal between canister strings.

A feed stream of cement, sand, and cement additives will be required by the process when grouting around the canisters and when installing plugs/seals. The exact makeup of the grout mixtures will depend on the conditions in the borehole and the grout performance requirements. These requirements include compatibility with high temperatures, high strength, low permeability, and high resistance to chemical alteration by brine as essential characteristics.

4.3.3 Products

There are no products in this operation. Wastes generated by the process are identified in Section 4.3.7.

4.3.4 Utilities Required

Process water, compressed air, and electrical power facilities will be supplied to the Emplacing–Borehole Sealing Facility.

4.3.5 Chemicals Required

The primary process materials required for the emplacement and borehole sealing process are those required to prepare the borehole sealants. These include chemical additives such as water reducers, superplasticizers, silica fume, fly ash, extenders, and swelling additives.

4.3.6 Special Requirements

A materials control and accountability system with nondestructive assays and computer systems is required for plutonium material control and accountability (MC&A).

4.3.7 Waste Generated

4.3.7.1 Emissions and Effluents

The primary atmospheric emissions produced by this process are the dusts raised by the handling of solid cement, sand, aggregate, silica fume, and fly ash during the preparation of the concretes and sealants. Exhausts will be produced by the diesel engines of the power generation sets.

4.3.7.2 Solid and Liquid Wastes

The primary wastes produced by this process are uncontaminated solid waste cement, sand, and aggregates. The solid wastes will be disposed of at a landfill.

No wastewater will be generated by the emplacement and borehole sealing process. Water produced from the borehole, however, will be sampled for radioactivity and brine chemical composition. The sample is first tested for radioactivity from any damaged emplacement canisters and, if not contaminated, is returned to the mud pits. If the water is contaminated, it is routed to the Process Wastewater Treatment facility in the Main Facility area. If contamination is discovered, corrective action will be taken to contain it.

4.4 Waste Management Facility

4.4.1 Waste Management

The waste management of the deep borehole disposal facility includes waste handling and treatment operations for processing transuranic (TRU) waste, low-level waste (LLW), hazardous mixed waste (MW), and industrial waste in aqueous, organic liquid, or solid form generated by borehole disposition operations or by site activities. The waste management is in accordance with DOE Order 5820.2A and the Resource Conservation and Recovery Act (RCRA). TRU waste generated by borehole operations is based on disposal to the Waste Isolation Pilot Plant (WIPP) in accordance with WIPP Waste Acceptance Criteria. The waste management process flow diagram is shown in Figure 4.4.1-1.

4.4.1.1 Waste Treatment and Storage Systems

The radioactive wastes are processed in a waste handling facility adjacent to the receiving and process building. The waste treatment process includes assay examination, sorting, separation, concentration, size reduction, special treatment, and thermal treatment. The wastes are converted to water meeting effluent standards, grouted cement, or compacted solid waste as final form products for disposal. Solid TRU wastes are packaged, assayed, and certified before they are shipped to the WIPP for permanent emplacement. Low-level solid wastes are surveyed and shipped to a shallow land burial site for disposal. A small quantity of solid mixed waste is packaged and shipped to a DOE waste treatment facility pending future processing. The waste treatment processing also performs equipment and waste container decontamination operations.

4.4.1.2 Utility Wastewater Treatment

Utility Wastewater Treatment treats wastewater (cooling tower blowdown and boiler blowdown) generated by utility operations by reverse osmosis followed by evaporation and spray drying. Reclaimed water is used as makeup to the cooling water tower. Dry residue is disposed of as solid industrial waste.

4.4.1.3 Process Waste Management

The Process Waste Management Facility contains equipment and processes for treating conventional, hazardous, radioactive, and mixed liquid wastes. Ancillary facilities are provided such as the electrical room, control room, process laboratory and changehouse/boundary control station, mechanical (HVAC) room, lunch/break room, and offices. The facilities are designed to the requirements of a moderate-hazard facility, as defined by UCRL-15910 (DOE-STD-1020-92) and DOE Order 6430.1A.

Process Waste Treatment treats wastewater generated by processes in the Surface Processing and Emplacing–Borehole Sealing facilities. Wastewater originating in the borehole array area is pumped through underground pipes to the Process Waste Treatment facility. Such wastewater is expected to primarily consist of mopwaters and cleaning solutions, emplacement canister sealants and additives,

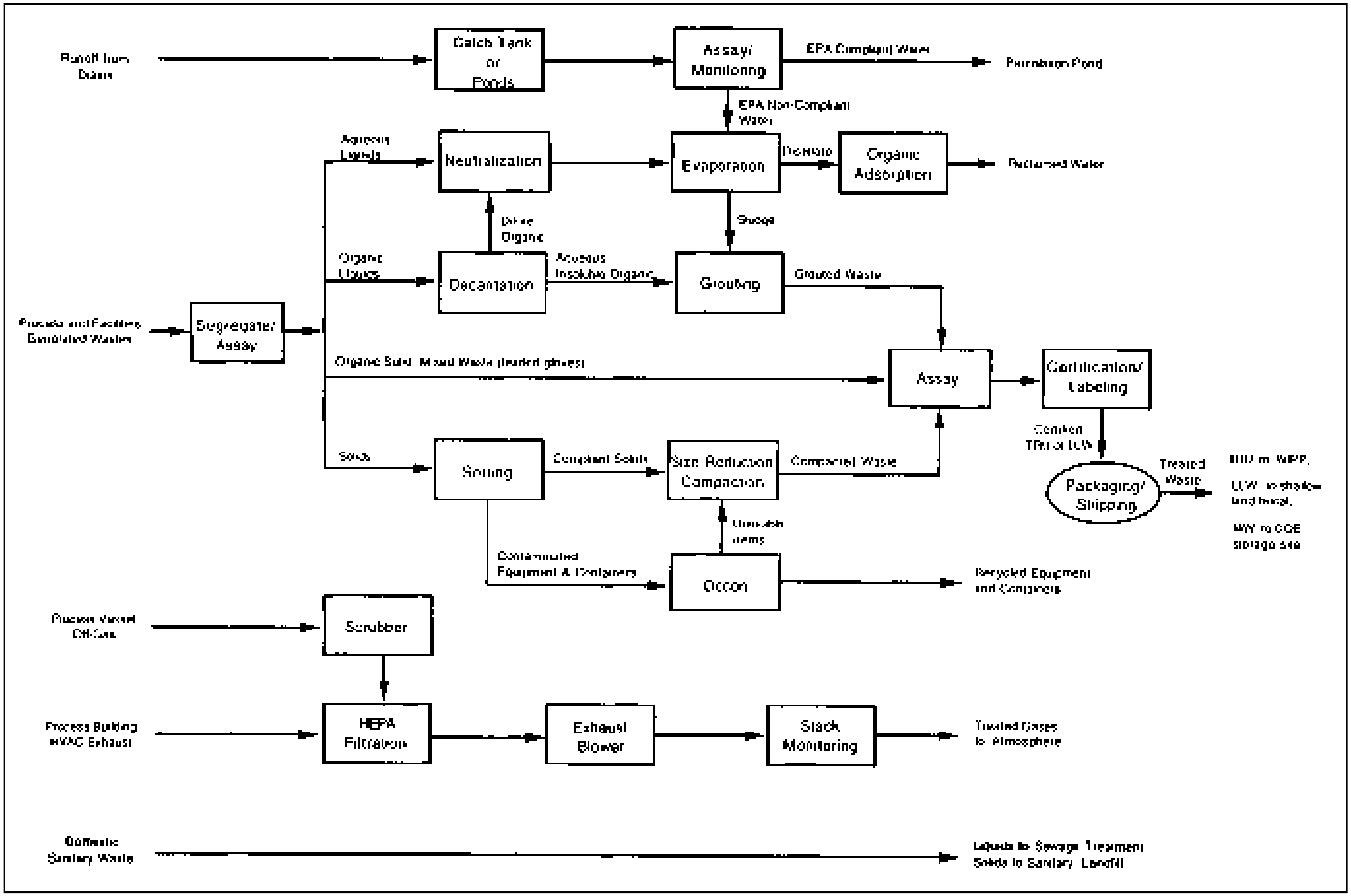

Figure 4.4.1-1. Waste Management Process Flow Diagram.

drilling mud additives, grout additives, and machine coolant wastes.

A substantial amount of wastewater will be generated by the drilling facility as overflow water from drilling mud settlement ponds. Water pumped from the borehole during drilling, emplacing, and sealing operations requires treatment. Treatment processes are arranged so that cross-contamination of radioactive, hazardous, and conventional wastes will not occur. Provisions will be made to obtain samples of wastewater for analysis before treatment.

Support facilities include a chemicals storage room and mixing area located outside any radiation control areas. A control room, laboratory, offices, lunch/break room, lavatories, electrical service room, and mechanical service room will be provided. Appropriate boundary controls must be implemented to isolate activities that take place in radiation control zones.

Effluent from Process Waste Treatment is designated as reclaimed water recycle and is used as makeup water to the cooling tower.

4.4.1.4 Sanitary Wastewater Treatment

Sanitary Wastewater Treatment is designed to handle plant sanitary sewage and includes the collection piping system from all plant facilities. Hazardous chemicals, process waters, and contaminated streams will be kept out of the system. Waste from wash stations is collected in tanks and sampled for contamination before release to Sanitary Wastewater Treatment. If any streams are found to be contaminated, the wastewater is discharged to Process Wastewater Treatment. The treated wastewater effluent from Sanitary Wastewater Treatment is designated as reclaimed water recycle and is used as makeup water to the cooling tower. Sludge generated by Sanitary Wastewater Treatment is dewatered and shipped to an on-site sanitary/industrial landfill. The treatment system consists of primary, secondary, and tertiary treatment with disinfectant. Necessary controls will be implemented so that radionuclides will not be present in sanitary wastewater.

4.4.1.5 Waste Heat Management

Waste heat generated from process water cooling and HVAC chiller systems is dissipated to the environment by a cooling tower system in the Support Utilities Area.

4.4.1.6 Storm Water Management

Storm Water Management impounds all storm water runoff from the facility and includes retention facilities and monitoring equipment. Discharged water can be used as cooling tower makeup or is discharged to natural drainage. If the storm water were to become contaminated, it would be treated before discharge.

4.4.2 Waste Management Feeds

Radioactive contaminated feeds may arise from processing incoming canisters and from process wash liquids and excess water being output from the borehole. Additional contaminated and uncontaminated waste process feeds arise from sealant residues, contaminated reagent containers, deformed plutonium shipping containers, wipes, rags, paper clothing, TCA cleaning solvent, and spent pump oils. Feeds from drilling include briny water and solid rock cuttings. Feeds from emplacement and borehole sealing include unconsumed solid waste cement, sand, and aggregates that contain chemicals used with concrete and sealants and may include contaminated wastewater.

4.4.3 Waste Management Function Products

Waste management function products may include certified TRU, LLW, or MW. Domestic sanitary waste will be processed into liquids for sewage treatment and solids for sanitary landfill.

4.4.4 Waste Management Function Special Requirements

Waste treatment processes require decontaminating solutions for decontamination.

5. RESOURCE NEEDS

5.1 MATERIALS/RESOURCES CONSUMED DURING OPERATION

5.1.1 Utilities Consumed

5.1.1.1 Surface Processing Facility

The estimated annual utility requirements for operation of the Surface Processing Facilities are shown in Table 5.1.1.1-1.

5.1.1.2 Drilling and Emplacing–Borehole Sealing

The utilities required by the drilling and emplacement–sealing operations are summarized in Table 5.1.1.2-1. The values represent the average annual expected consumption. Water usage is shown in Table 5.1.3.2-1, because the water is consumed with the materials listed in that table.

5.1.2 Water Balance

The raw water requirement for the Deep Borehole Disposal Facility is about 165.4 million liters per year (Dry Site), of which 90.8 million liters is consumed by the main facility area and 74.6 million liters is consumed by the Drilling and Emplacing–Borehole Sealing Facilities in the borehole array area. The Raw Water Subsystem includes production wells, supply pumps, and transfer piping to the Facility Water Subsystem. Figure 5.1.2-1 shows the Annual Water Balance (Dry Site) for the Facility. There will be no significant difference in the raw water requirement

Table 5.1.1.1-1. Utilities Consumed by the Surface Processing Facility During the Operation Period.

Utility	Annual Average Consumption	Peak Demand(1)
Electricity	6,000 MWh	2 MW
Diesel Fuel	17,400 L	N/A
Natural Gas	5,097,600 m^3 (2)	N/A
Raw Water (Dry Site)	90,800,000 L	N/A
Raw Water (Wet Site)	90,800,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

(2) Standard cubic meters measured at 1.034 kg/cm^2 (14.7 psia) and 15.6°C (60°F).

Table 5.1.1.2-1. Utilities Consumed by the Drilling and Emplacing-Borehole Sealing Facilities During the Operation Period.

Utility	Annual Average Consumption	Peak Demand(1)
Electricity	500 MWh	0.3 MW
Gasoline and Diesel Fuel	757,000 L	750 L
Natural Gas	0 m^3 (2)	N/A
Raw Water (Dry Site)	74,600,000 L	N/A
Raw Water (Wet Site)	74,600,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

(2) Standard cubic meters measured at 1.034 kg/cm^2 (14.7 psia) and 15.6°C (60°F).

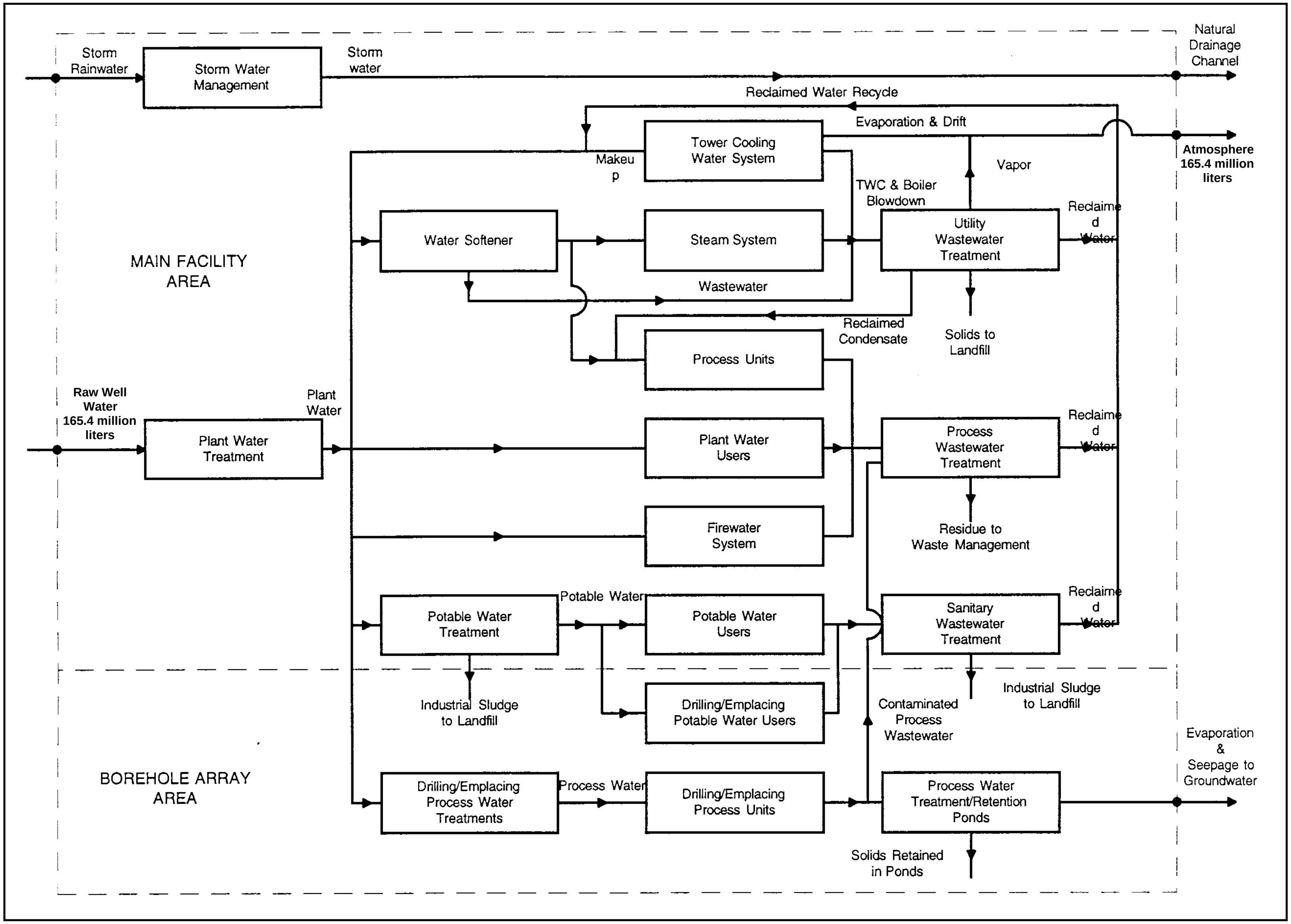

Figure 5.1.2-1. Deep Borehole Disposal Facility Water Balance (Dry Site).

between dry and wet sites. The main difference between dry and wet sites on the water supply system will be will be the following: (1) the source of raw water will be a river or lake for a wet site and water wells for a dry site; (2) storm water impounding ponds and drains will be smaller for a dry site; (3) evaporation and groundwater seepage losses from retention ponds will be greater for a dry site; and (4) the cooling water tower system must be larger for a dry site.

5.1.3 Chemicals Consumed

5.1.3.1 Surface Processing Facility

The estimated material consumptions during the entire emplacement operation period of the Surface Processing Facilities are listed in Table 5.1.3.1-1.

5.1.3.2 Drilling and Emplacing–Borehole Sealing

The materials required for the drilling and emplacement–sealing operations are listed in Table 5.1.3.2-1. Requirements are given for the entire project, not annual usage. The steel will be used for the borehole casing. The bentonite will be used in cements and drilling fluids. The sodium citrate and silica flour will be used in the cement mixes. The polymers will be used in the drilling mud and the cement mixes. Some of the polymers and bentonite will become waste from the drilling process. The water will be used for drilling fluid (mud) and for producing the cements. The air will be used by compressors for the drilling process.

Table 5.1.3.1-1: Annual Chemicals or Materials Consumed by the Surface Processing Facility During Operation.

Nonradiological Material	Quantity
Solids	
Steel (emplacement canisters)	60 t
Sealant	1,200 t
Decon detergent	1,360 kg
Non-ionic polymer (water treatment)	136 kg
Phosphates/phosphonates (water treatment)	907 kg
Gases	
Nitrogen gas	120 cylinders

Table 5.1.3.2-1. Nonradiological Materials Consumed by the Drilling and Emplacing-Borehole Sealing Facilities During the Operation Period.

Nonradiological Material	Quantity
Solids	
API Class D, G, and F Cements	36,300,000 kg
Steel (Casing, canisters)	9,530,000 kg
Bentonite	907,000 kg
Sodium Citrate	363,000 kg
Silica Flour	363,000 kg
Polymers	363,000 kg
Liquids	
Water (for mud and cement, included in Raw Water in Table 5.1.1.2-1)	65,600,000 L

5.1.4 Radiological Materials Required

There are no radioactive material requirements other than the 50 t of plutonium feed material over the 10-yr period of operation of the Deep Borehole Disposal Facility.

5.2 MATERIALS/RESOURCES CONSUMED DURING CONSTRUCTION

5.2.1 Utilities

The estimated total energy resources and water consumption requirements during construction of the borehole surface facilities are shown in Table 5.2.1-1.

5.2.2 Nonradiological Materials

The estimated quantity of materials required for construction of the borehole surface facilities is shown in Table 5.2.2-1.

5.2.3 Land Use

The Deep Borehole Disposal Facility requires approximately 4 hectares (10 acres) of land for construction laydown and warehousing and 2 hectares (5 acres) for construction parking.

Table 5.2.1-1. Utilities Consumed During the Construction Period.

Utility	Total Consumption	Peak Demand(1)
Electricity	1,800 MWh	0.8 MW
Diesel Fuel	3,600,000 L	N/A
Natural Gas	2,390,000 L	N/A
Propane	360,000 L	N/A
Raw Water	45,400,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

Table 5.2.2-1. Materials Consumed During the Construction Period.

Material	Total Quantity
Concrete	27,000 m^3
Steel	6,400 t
Copper	90 t
Lumber	1,500 m^3
Asphalt	3,700 t

6. EMPLOYMENT NEEDS

Manpower and staffing requirements for construction and operation of the Deep Borehole Disposal Facility are estimated in the following subsections.

6.1 Employment Needs During Operation

The estimated staffing requirements for operation of the Deep Borehole Disposal Facility are shown in Table 6.1-1. A 10-yr emplacement operation is assumed.

6.2 Badged Employees at Risk of Radiological Exposure

Approximately 60% of the personnel listed in Table 6.1-1 would routinely work inside the radiological area to operate and maintain the Deep Borehole Disposal Facility. Accordingly, 60% of facility personnel would be classified as "radiological occupational workers" at risk for radiological exposure. The radiological impact on average workers attributed to the disposal operation is less than 13 mrem/yr, based on a previous borehole nuclear waste disposal study.

6.3 Employment Needs During Construction

Table 6.3-1 gives the estimated field labor force schedule for construction of the Deep Borehole Disposal Facility. A 3-yr construction schedule is assumed.

Table 6.1-1. Employment During Operation.

Labor Category	Number of Employees
Officials and Managers	23
Professionals	45
Technicians	40
Office and Clerical	8
Craft Workers	82
Operators	98
Laborers	6
Service Workers	40
Total employees	**342**

Table 6.3-1. Number of Construction Employees Needed by Year.

Employees	Year 1	Year 2	Year 3
Total Craft Workers	280	785	425
Construction Management and Support Staff	30	85	45
Total Employment	**310**	**870**	**470**

7. WASTES AND EMISSIONS FROM THE DEEP BOREHOLE DISPOSAL FACILITY

Wastes and emissions as described in the SFM PEIS may not correlate exactly with those in this report because of differing categorizations.

7.1 Wastes and Emissions During Operation

The annual wastes and emissions released during operation of the Deep Borehole Disposal Facility are estimated in the following subsections. A 10-yr emplacement operation schedule is assumed.

7.1.1 Emissions

Estimated annual quantities of air pollutant emissions from operation of the Deep Borehole Disposal Facility are shown in Tables 7.1.1-1 and 7.1.1-2. The emissions are based on the annual fuel and gas consumption estimated in Tables 5.1.1.1-1 and 5.1.1.2-1.

Chemical processes that may lead to the release of contaminants over time are unlikely in the relatively short times associated with the canister emplacement, backfill, and stemming barrier processes. Mechanical accidents in which the containment capsules (canisters) are breached are more likely.

Table 7.1.1-1. Chemical Emissions Generated by the Surface Processing Facility During the Operation Period.

Chemical	Annual Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	82
Nitrogen Oxides	998
Particulates	9,072
CO	363
Hydrocarbons	91
Other Chemicals	
Volatile Organic Compounds	trace
Water Vapor (cooling tower)	45,450,000

Table 7.1.1-2. Chemical Emissions Generated by the Drilling and Emplacing-Borehole Sealing Facility During the Operation Period.

Chemical	Annual Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	2,740
Nitrogen Oxides	29,900
Particulates	2,740
CO	10,900
Hydrocarbons	2,740
Other Chemicals	
None	

Estimated radiological release to environment during operation of the Deep Borehole Disposal Facility is shown in Table 7.1.1-3. The estimated release is based on the total curie inventory of radionuclides stored and processed annually in the Deep Borehole Disposal Facility with the radioactivity release factor from a previous design report (DOE/ET-0028) for a plutonium storage facility, whose operational characteristics very similar to those of the Deep Borehole Disposal Facility.

7.1.2 Solid and Liquid Wastes

The type and quantity of solid and liquid wastes expected to be generated from operation of the Deep Borehole Disposal Facility and the final waste products after treatment are shown in Tables 7.1.2-1 and 7.1.2-2. The waste generations are based on factors from historic data on building size, utility requirements, and facility work force estimated in Table 6.1-1.

7.1.2.1 High-Level Wastes

No high-level radioactive waste is generated from operation of the Deep Borehole Disposal Facility.

7.1.2.2 Transuranic Wastes

Transuranic wastes will be generated from process and facility operations, equipment decontamination, failed equipment, and used tools. TRU wastes are treated on-site in a waste handling facility to form grout or compact solid waste. Treated TRU waste products are packaged, assayed, and certified before they are shipped to the Waste Isolation Pilot Plant (WIPP) for disposal.

7.1.2.3 Low-Level Wastes

Low-level wastes generated from operations of the Deep Borehole Disposal Facility are treated by sorting, separation, concentration, and size reduction. Final LLW products are converted to solid form, surveyed for radioactivity, and shipped to a shallow land burial site for disposal.

7.1.2.4 Mixed Transuranic Wastes

A small quantity of solid mixed waste, mainly rubber gloves and leaded box-gloves in the waste handling facility, will be generated from operation of the Deep Borehole Disposal Facility. The mixed waste is packaged and shipped to another DOE waste management facility (e.g., INEL, Idaho) for storage pending final treatment and disposal.

7.1.2.5 Mixed Low-Level Wastes

Mixed wastes generated from the Deep Borehole Disposal Facility with radioactivity below TRU level (100 nCi/g) will be classified as mixed low-level wastes and will be treated as described in Section 7.1.2.4 for mixed TRU wastes.

7.1.2.6 Hazardous Wastes

Hazardous wastes will be generated from chemical makeup, reagents for support activities, and lubricants for drilling and emplacement machinery. Hazardous wastes will be managed and hauled to a commercial waste facility offsite for treatment and disposal according to EPA RCRA guidelines.

7.1.2.7 Nonhazardous (Sanitary) Wastes

Nonhazardous sanitary liquid wastes generated in the Deep Borehole Disposal Facility are transferred to an onsite sanitary waste system for treatment. Nonhazardous solid wastes such as domestic trash and office waste are hauled to an offsite municipal sanitary landfill for disposal.

Table 7.1.1-3. Radiological Emissions Generated by the Surface Processing Facility During the Operation Period.

Radioactive Element	Annual Emissions (nCi)
Atmospheric Emissions	
Pu total	1.3
Other Actinides (Am-241)	0.2
Liquid Effluents	
Pu total	2
Other Actinides (Am-241)	4

Table 7.1.2-1. Annual Spent Fuel and Waste Volumes During Operation of Surface Facilities.

Category	Generated Quantities		Post-Treated	
	Solid (m^3)	Liquid (L)	Solid (m^3)	Liquid (L)
Spent Fuel	0	0	0	0
High–Level Waste (HLW)	0	0	0	0
Transuranic Waste (TRU)	0.153	151	0.153	0
Low–Level Waste (LLW)	4.59	2,270	4.59	0
Mixed Transuranic Waste	0.0382	0	0.0382	0
Mixed Low-Level Waste	0	0	0	0
Hazardous Waste	15.3	1,890	15.3	1,890
Nonhazardous (Sanitary) Wastes				
Dry Site	306	10,600,000	306	10,600,000
Wet Site	306	10,600,000	306	10,600,000
Nonhazardous (Other) Wastes				
Dry Site	0	6,800,000	0	6,800,000
Wet Site	0	6,800,000	0	6,800,000
Recyclable Wastes	0	0	0	0

Table 7.1.2-2. Solid and Liquid Wastes Generated by the Drilling and Emplacing-Borehole Sealing Facilities During the Operation Period.

Category	Annual Quantities	
	Solid	Liquid
Hazardous Wastes		
Oil/Antifreeze/Hydraulic Fluid		108,000 L
Rags, etc.	1,814 kg	
Nonhazardous Sanitary Wastes	Section 7.1.2.7	Section 7.1.2.7
Nonhazardous Wastes		
Rock Cuttings from Borehole	1,220 m^3	
Bentonite	31,800 kg	
Polymers	6,800 kg	

7.1.2.8 Nonhazardous (Other) Wastes

Other nonhazardous liquid wastes (e.g., cooling tower and evaporator condensate) generated from facilities support operations are collected in a catch tank and sampled before reclamation for other use or release to the environment.

The combined waste from the drilling and emplacement operations is summarized in Table 7.1.2-2. The waste consists of rock cuttings, bentonite, and polymers used during drilling. These wastes will all end up in the mud pits. It is customary in the drilling industry to leave these wastes in the mud pits rather than ship them off site. After drilling is complete, the pits are generally filled with earth and leveled. There is expected be no treatment of these wastes unless testing indicates otherwise. The rock cuttings are shown in the table only as a volume, because the rock will vary in density.

7.2 Wastes and Emissions Generated During Construction

The estimated wastes and emissions generated during construction of the Deep Borehole Disposal Facility are given in the following sections. A 3-yr construction schedule is assumed.

7.2.1 Emissions

Estimated emissions from construction activities of the Deep Borehole Disposal Facility during the peak construction year are shown in Table 7.2.1-1. The emissions are based on the construction land disturbance and vehicle traffic (for dust particulate pollutant) and on the fuel and gas consumption (for chemical pollutants) estimated in Tables 5.2.1-1 and 5.2.2-1. The peak construction year is based on a construction schedule as the labor force distribution shown in Table 6.3-1.

7.2.2 Solid and Liquid Wastes

Estimated total quantity of solid and liquid wastes generated from activities associated with construction of the Deep Borehole Disposal Facility is shown in Table 7.2.2-1. The waste generations are based on factors from historic data on construction area size and construction labor force estimated in Table 6.3-1. Solid wastes are hauled offsite for disposal during the construction period.

7.2.2.1 Radioactive Wastes

No radioactive wastes are generated during construction of the Deep Borehole Disposal Facility.

7.2.2.2 Hazardous Wastes

Hazardous wastes generated from construction activities, such as motor oil, lubricant, and drilling fluid from vehicles and drilling machinery, will be managed and hauled to a commercial waste facility offsite for treatment and disposal according to EPA RCRA guidelines.

7.2.2.3 Nonhazardous Wastes

Solid nonhazardous wastes generated from construction activities, e.g., construction debris and rock cuttings, will be disposed of in a sanitary landfill. Liquid nonhazardous wastes are treated with a portable sanitary treatment system or hauled off-site for treatment and disposal.

Table 7.2.1-1. Emissions During the Peak Construction Year.

Chemical	Total Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	8,390
Nitrogen Oxides	102,000
Particulates (dust)	680,000
CO	658,000
Hydrocarbons	8,390
Other Chemicals	
Volatile Organic Compounds	trace

Table 7.2.2-1. Total Solid and Liquid Wastes Generated During Construction.

Waste Category	Quantity
Hazardous Solids	77 m^3
Hazardous Liquids	11,360 L
Nonhazardous Solids	
Concrete	421 m^3
Steel	181 t
Sanitary	994 m^3
Other	92 m^3
Nonhazardous Liquids	
Sanitary	30,300,000 L
Other	5,680,000 L

8. DESIGN PROCESS FOR ACCIDENT MITIGATION

Purpose

The Deep Borehole Disposal Facility for disposing of excess weapons-usable fissile materials (approximately 50 t) is a Hazard Category 1 facility as defined in DOE-STD-1027-92. As such, the facility will require a detailed Safety Analysis Report (SAR) and Risk Assessment under DOE Order 5480.23 before it is licensed for operation. In the PEIS phase, an accident analysis and risk assessment must be performed to provide a broad evaluation of potential accidents, and the basic design and mitigative features must be incorporated in the facility to reduce the impact of the accidents. This requires a qualitative evaluation of the risk of facility operation to public health and safety, including the magnitude of release of Pu outside the facility due to the postulated bounding accidents. The frequency or probability of the accidents or events is estimated qualitatively; a quantitative frequency range is assigned to each qualitative frequency class. This approved approach complies with DOE-STD-3009-94, the guidance document for DOE Order 5480.23. This document provides prescriptive methods for hazard and accident analysis for the Safety Analysis Report for facilities of Hazard Categories 1, 2, and 3 based on a graded approach.

According to DOE-STD-3009-94, Chapter 3, a hazard analysis must be performed as a prerequisite to a quantitative accident analysis that forms a part of the SAR. This accident analysis is performed to provide guidance for the design of structures, systems, and components (SSCs) classified as Safety Related and/or Safety Significant. The accident analysis is performed at two levels. The first level consists of deterministic analyses for sizing and designing the SSCs for safe operation. The second level consists of a Probabilistic Risk Assessment (PRA) for estimating the overall risk of facility operation to workers and the public. The PRA supplements the deterministic analysis of the first level to provide insight into the hidden vulnerabilities in the design and operation of the facility. The PRA is performed at different levels of detail depending on the regulatory compliance requirements and to support facility life-cycle management decisions. The risk assessment for regulatory compliance is performed to determine the risk posed by facility operation to workers and the public and to ensure that DOE safety goals are met by satisfying the evaluation guidelines of DOE-STD-3005-94 (DRAFT).

Scope

The risk assessment must show that the facility will satisfy all appropriate ES&H safety requirements and national and international regulations for each of two operational phases: (1) Pre-Closure Construction, Operating, and Closure Period (assumed to be about 10 yr in duration) and (2) Post-Closure Performance Period, which extends from the time the borehole is sealed and plugged to an indefinite, geologically long time. A full-fledged risk assessment, covering both the Pre-Closure and the Post-Closure phases of facility construction, operation, closure, and post-closure performance, cannot be performed in the current pre–conceptual design stage of the facility because of the lack of site characteristics data and detailed facility systems data and of the resources and time required to perform the analyses. It is therefore assumed that only a qualitative risk assessment of limited scope will be performed on the basis of the following assumptions and data provided in this report:

1. Risk assessment is limited to the Pre-Closure Phase of the facility and will not address its Post-Closure Phase performance. The Post-Closure phase requires long-term performance analyses that require a program of research to develop the necessary information. This analysis is therefore deferred to a future study. The quantitative, full-scope risk assessment using system models for the Pre-Closure phase will be performed along with the SAR preparation stage in the development and design of the facility.

2. Bounding accident scenarios are classified into Design Basis Accidents and Beyond Design Basis Accidents.

3. The frequency of each accident scenario will be based on engineering judgment, because the design or site characteristics of the facility are not developed well enough to justify use of rigorous risk analysis techniques.

4. Accident frequencies will be assigned qualitative levels of the annual probability of occurrence according to DOE-STD-3009-94:

   Anticipated ($10^{-1} \geq p > 10^{-2}$)
   Unlikely ($10^{-2} \geq p > 10^{-4}$)
   Extremely Unlikely ($10^{-4} \geq p > 10^{-6}$)
   Beyond Extremely Unlikely ($10^{-6} \geq p$).

5. An estimate of the amount of each hazardous material at risk in an accident.

6. An estimate of the fraction of each hazardous material at risk that becomes airborne in respirable form.

7. An estimate of the fraction of each respirable airborne hazardous material in each accident that is removed by the ventilation system filters.

8.1 Operational and Design Basis, and Beyond Design Basis Bounding Accidents

8.1.1 Operational and Design Basis Accidents

In this section, the different categories of Operational and Design Basis Accidents are first described. Each accident scenario is then defined in sufficient detail to develop the basis for estimating the accident frequency and the release rates for the hazardous materials. The information provided for these separate accident scenarios are summarized in Table 8.1.1.19-1 of Section 8.1.1.19.

The major accident categories in this class are defined according to DOE-STD-3009-94, Section 3.4.2:

- ***Category 1:*** Natural Phenomena Events/Accidents for the site (e.g., earthquakes, wind/tornadoes, floods).
- ***Category 2:*** External Man-Made Accidents (e.g., aircraft crashes, nearby industrial facility accidents).
- ***Category 3:*** Internal Operational or Process-Related Accidents (e.g., fires, explosions, spills, criticality events).

These accidents are analyzed to evaluate the capability of the facility structures, systems, and components to limit the risk to the public to within the acceptable limits proposed in the evaluation guidelines.

Category 1: Natural Phenomena Events/ Accidents

Earthquake Hazard

The generic site description for the Deep Borehole Disposal Facility recommends the selection of a U.S. site in a region of high tectonic and seismic stability (e.g., a site where there are no recorded earthquakes with a Mercalli intensity over V). Using this guideline, the site is likely to be chosen in the Seismic Zone 1 according to the Uniform Building Code (UBC). This zone has a maximum acceleration of 0.075 g (see Figure 23-2 of UBC-1991). The design of the facility structures, systems, and components will be based on this maximum acceleration for the Design Basis Earthquake (DBE) and will follow the design criteria of DOE-STD-1020-94 for Performance Category PC-3 (see definition in DOE Order 5480-28). From Table 2-1 of DOE-STD-1020-94, for Performance Category PC-3, the seismic hazard exceedance level is 5×10^{-4} with a return period of 2000 yr for sites distant from tectonic plate boundaries. The preferred site, as recommended in the generic site description, is in an extremely stable tectonic region distant from tectonic plate boundaries. Therefore, the use of the UBC seismic zone 1 “g” level for the DBE, and design criteria from DOE-STD-1020-94 for design of the SSCs, are justified. The risk due to this earthquake hazard will be negligible. The effect of an earthquake on the surface facilities will be more pronounced than that on the emplacement region of the deep borehole if no active faults are present near the emplacement region. The absence of active faults is an important site selection criterion for the Deep Borehole Disposal Facility.

Wind/Tornado Hazard

The generic site description for the facility location assumes a windy location, with winter blizzards and spring and summer tornadoes. Chapter 3 (p. 3-1) of DOE-STD-1020-94 states that “wind speeds associated with straight winds typically are greater than tornado winds at annual exceedance probabilities greater than approximately 1×10^{-4}.” Tornado design criteria are specified only for SSCs in Performance Categories 3 and higher, where hazard exceedance probabilities are less than 1×10^{-2}. In determining wind design criteria for Performance Categories 3 and higher, the first step is to determine if tornadoes should be included in the criteria. The decision can be made on the basis of geographical location, using historical tornado occurrence records. Because the facility design will have to follow DOE-STD-1020-94, Chapter 3 for Wind/Tornado design with appropriate missile criteria for Performance Category 3 given in Table 3-1 of the standard, it is expected that the consequence due to wind hazard will be insignificant. It is also assumed that adequate administrative control will be established for severe blizzard conditions by a sitewide warning and response plan. High wind and blizzard conditions are therefore screened out because the consequences are negligible. Site-specific quantitative probabilistic wind hazard analysis will be performed only when a particular site (rather than a generic site) is selected.

Flood Hazard

The generic site description recommends that, for the elimination of the flood hazard, the site should be selected to lie above the flood plain of the worst 50 to 100-yr floods in the historical record for the region. According to DOE-STD-1020-94, Chapter 4 (p. 4-11), the flood design criteria for SSCs of Performance Category 3 are that "…the SSCs in this category should be located above flood levels whose mean annual probability of exceedance is 10^{-4} including the event combinations shown in Table 4-2…" of the standard. When the specific site is selected, the design criteria established in this standard should be used for the facility design. It is therefore assumed that the consequence due to the design basis flood hazard at the facility is negligible.

Category 2: External Man-Made Accidents

External events that originate outside the facility (e.g., aircraft crash, nearby industrial facility accident) are site-specific and are not considered at the pre–conceptual design phase and/or the PEIS preparation phase because no site has been selected. However, as in the case of natural phenomena, the facility SSCs must be designed to withstand the hazards due to the dominant external events such as the ones mentioned above. Therefore, it is assumed in this evaluation that the consequences due to these external events are negligible.

Category 3: Internal Operational or Process-Related Accidents

Accidents in this category arise from process malfunctions, equipment failures, human errors, etc. Accidents in this category are usually unrelated to Category 1 and Category 2 events, but they may be initiated by precursor events in these two categories.

8.1.1.1 Earthquake (Category 1)

The design basis earthquake (DBE) for the Deep Borehole Disposal Facility will be chosen in accordance with DOE-STD-1020-94. Safety class systems, structures, and components (SSCs) are designed to withstand the DBE. Earthquakes exceeding the magnitude of the DBE are "extremely unlikely" accidents as defined in DOE-STD-3009-94. Earthquakes of a magnitude that could cause the failure of safety class SSCs are considered "extremely unlikely" events. Given the safety class items assumed for the Deep Borehole Disposal Facility, it is reasonable to assume that the occurrence of an earthquake that would cause the release of radioactive material or an accidental criticality event is "extremely unlikely" (as defined in DOE-STD-3009-94). Because the material at risk is always contained in sealed containers, and because there is no direct processing of these materials in this facility design, there will be no earthquake-induced releases.

Mitigation features: The Deep Borehole Disposal Facility will be sited at a geographic location with low seismicity; process equipment will be fastened by bolts or tied down to reduce earthquake damage.

8.1.1.2 Tornado (Category 1)

The design basis tornado (DBT) for the Deep Borehole Disposal Facility will be chosen in accordance with DOE-STD-1020-94. Safety class systems, structures, and components (SSCs) are designed to withstand the DBT and DBT-generated missiles. Tornadoes exceeding the DBT magnitude are "extremely unlikely" accidents as defined in DOE-STD-3009-94. Tornadoes of sufficient energy to cause the failure of safety class SSCs are considered "extremely unlikely" events. Given these SSCs, it is reasonable to assume that it is "extremely unlikely" (as defined in DOE-STD-3009-94) that a tornado would cause a release of radioactive material at the Deep Borehole Disposal Facility.

Mitigation features: Tornado dampers will be installed in the Surface Processing Facility.

8.1.1.3 Flood (Category 1)

Flooding is of particular concern at plutonium processing facilities because of the potential for nuclear criticality accidents. As described in the generic site description, the Deep Borehole Disposal Facility site will be selected to lie outside the 100-yr flood plain in the region selected for the facility; this is consistent with the site description given in Section 3. Furthermore, the facility will be designed to preclude flooding of plutonium storage and processing areas. Safety class systems, structures, and components (SSCs) are designed to withstand the DBF. Floods exceeding the DBF magnitude are extremely unlikely accidents. Given these SSCs, it is reasonable to assume that it is "extremely unlikely" (as defined in DOE-STD-3009-94) for a flood to cause a release of radioactive material or an accidental criticality event at the Deep Borehole Disposal Facility.

Mitigation features: The Surface Processing Facility will be constructed above flood line to preclude flooding in plutonium storage and processing areas.

8.1.1.4 Plutonium Storage Container Breakage During Storage (Category 3)

It is postulated that a plutonium storage container is ruptured because of overpressurization of the container. Overpressurization could occur as a result of volume expansion caused by complete oxidation of Pu metal buttons stored in cans or by pressure buildup due to radiolysis of residual moisture in PuO_2 and helium gas from alpha decay of Pu and daughter products. Respirable Pu fines are released to the storage area and are collected by the ventilation system. The particle-laden gases pass through the ventilation system filters, and the residual fines are released to the environment. A PCV contains approximately 4.5 kg of Pu, so at most 4.5 kg of Pu is at risk in this accident scenario. Based on experience at Hanford, 1% of the Pu would be expected to escape from the can. Based on Walker (1981), 0.1% of the leaked PuO_2 is resuspended and becomes airborne as respirable fines. This release is to the Zone 1 ventilation area. Assuming a three-stage HEPA filter system, 10^{-8} of the airborne material will penetrate the filtration system. Therefore, 10^{-13} of the material at risk will reach the environment. This is judged to be an "unlikely" accident (as defined in DOE-STD-3009-94).

Mitigation features: Administrative procedure controls will be established for extremely careful container handling to reduce the likelihood of this type of accident. The radioactive material released is removed from the air stream by HEPA filters.

8.1.1.5 Plutonium Storage Container Breakage During Handling (Category 3)

It is postulated that a PCV is dropped and breaches in container-handling operations. The force of the drop ruptures the container and punctures both storage cans inside the container. The PuO_2 powder escapes from the ruptured container, and respirable PuO_2 fines are released to the process area and are collected by the ventilation system. The airborne fines that pass through the ventilation system filters are released to the environment. A PCV contains approximately 4.5 kg of PuO_2, so at most 4.5 kg of PuO_2 is at risk in this accident scenario. Based on Walker (1981), 0.1% of the leaked PuO_2 is resuspended and becomes airborne as respirable fines. Thus, 10^{-3} of the material at risk is released to the Zone 1 ventilation area. Assuming a three-stage HEPA filter system, 10^{-8} of the airborne material will penetrate the filtration system. Therefore, 10^{-11} of the material at risk will reach the environment. This is judged to be an "unlikely" accident (as defined in DOE-STD-3009-94).

Mitigation features: Administrative procedural controls will be established for extremely careful container handling to reduce the likelihood of this accident. Radioactive materials released are removed from the air stream by HEPA filters.

8.1.1.6 Emplacement Canister Dropped During Handling (Category 3)

It is postulated that an emplacement canister is dropped during handling. Because the height from which a drop might occur is small (reduced impact energy), the force of the drop fractures the 2R containers and the sealing material but does not rupture the emplacement canister. The plutonium fines are contained within the emplacement canister. An emplacement canister contains nine PCVs with a total of approximately 40.5 kg of Pu. Therefore, at most 40.5 kg of Pu is at risk in this accident, and there is no release of radioactivity. This is judged to be an "unlikely" accident (as defined in DOE-STD-3009-94).

Mitigation features: Administrative procedural controls will be established for extremely careful canister handling to reduce the likelihood of this accident.

8.1.1.7 On-Site Emplacement Canister Transportation Accident (Category 3)

An accident could occur during the transportation of an emplacement canister from the Surface Processing Facility to the Emplacing–Borehole Sealing Facility. It is postulated that a transportation package containing an emplacement canister is dropped from the transporter during the accident. The force of the drop fractures the emplacement canister but does not rupture the transportation package. An emplacement canister contains 40.5 kg of Pu, so at most 40.5 kg of Pu is at risk in this accident scenario. Because the Pu metal or PuO_2 is contained within the transportation package, there is no release of radioactivity in this accident scenario. Based on SAND80-1721, the likelihood of a truck accident involving severe impacts is 1.6×10^{-6} per truck kilometer. This is judged to be an "unlikely" accident (as defined in DOE-STD-3009-94).

Mitigation features: The transportation package will be designed with double containment to prevent fissile material release in transportation accidents.

8.1.1.8 Criticality During Emplacement Canister Filling (Category 3)

The potential for the occurrence of a criticality event exists in all process steps involving plutonium handling. The policy adopted for the prevention of criticality events will be based on a policy that at least three independent and concurrent equipment failures or operation errors must occur before a criticality accident is possible. Mishandling of the plutonium containers during handing operations could lead to a criticality accident. Administrative controls will be imposed to limit the number and separation of the Pu containers that may be present at one time during container transfer operations and during emplacement canister filling. The fissile material mass limits will be chosen to preclude criticality in the event of double batching, and automated accountability systems will be employed. However, these criticality controls depend to some extent on the correct functioning of administrative and operational procedures. It is postulated that additional Pu containers are introduced into the emplacement canister filling process area in violation of procedural controls and that a criticality accident occurs as a result of the containers being spaced too closely.

In accordance with the Nuclear Regulatory Guide 3.35, the criticality event would involve 10^{18} fissions in the initial pulse, followed by 47 additional pulses, for a total of 10^{19} fissions in 8 hr. The criticality event described here is estimated to result in 100% of the noble gas fission products and 25% of the halogen (iodine) radionuclides produced by the event becoming airborne. All of these radioactive materials would be released to the Zone 1 ventilation system, because the exhaust HEPA filters do not prevent the release of noble gases and halogens. This is judged to be a “extremely unlikely” accident (as defined in DOE-STD-3009-94).

8.1.1.9 Criticality Due to Plutonium Storage Container Spill (Category 3)

The minimum critical mass under full water reflection external boundary conditions is 12 kg of Pu for dry PuO_2 or 65 kg for fully moist PuO_2. Thus, a nuclear criticality could occur if Pu containers were damaged in handling and the mass of the spilled PuO_2 powder exceeded the critical mass. Because each contains only 4.5 kg of Pu, a criticality accident would require successively damaging several containers. Therefore, a nuclear criticality accident outside the storage container is judged to be an “extremely unlikely” accident (as defined in DOE-STD-3009-94).

Assuming that the accident is possible, the energy released in this accident would probably alter the critical configuration through dispersal of the fissile material and would reduce it to a subcritical state. In accordance with the Nuclear Regulatory Guide 3.35 (NUREG-3.35), the criticality events involve 10^{18} fissions in the initial pulse, followed by 47 additional pulses, for a total of 10^{19} fissions in 8 hr. The criticality event described here is estimated to result in 100% of the noble gas fission products and 25% of the halogen (iodine) radionuclides produced by the criticality event becoming airborne and being released to the environment.

Mitigation features: Administrative controls will be imposed to limit the number and proximity of Pu containers that may be present during handling operations.

8.1.1.10 Fire in Process Facility Area (Category 3)

The combustible loading in the process areas is very low because the processes do not involve any flammable materials. However, small electrical fires are possible. Such fires would be localized and extinguished by the fire protection system. In any event, the combustible loading is low enough that it is unlikely that radioactive materials would be released as a result of this fire. Therefore, the release of radioactivity as a result of a fire in the process areas is judged to be an “extremely unlikely” accident (as defined in DOE-STD-3009-94).

It is postulated that a large fire is possible in the process area for emplacement canister filling, that the plutonium containers are breached by the fire, and that the contents are exposed to the fire. The ventilation system removes plutonium-containing particulates from the area. The particle-laden gases pass through the ventilation system filters, and the residual fines are released to the environment. Because the emplacement canister filling area contains 40.5 kg of Pu for one fill batch, at most 40.5 kg of Pu is at risk in this accident scenario. Based on Walker (1981), 0.1% of the Pu at risk becomes airborne in respirable form. Thus, 10^{-3} of the material at risk is released to ventilation Zone 2 area. Assuming a two-stage HEPA filter system, the fraction of particles penetrating the filter would be 10^{-6} of those released. Therefore, 10^{-9} of the Pu at risk would potentially be released to the environment as a result of the fire.

Mitigation features: The facility design will include a fire suppression system and fire isolation barriers in the process areas. The minimum quantity of combustible material in the process areas will be maintained through administrative controls. The radioactive materials released are removed from the air stream by HEPA filters.

8.1.1.11 Failure of Ventilation Filter (Category 3)

Ventilation filter failure could occur in a process ventilation system. A HEPA filter could fail because of moisture collection on the filter, excessive pressure loading from an exhaust blower, excessive heat from a fire, or mechanical shock. Failure of the HEPA filter alone is not expected to result in the release of radioactive particulates. This is judged to be an "anticipated" accident (as defined in DOE-STD-3009-94).

Mitigation features: The release of radioactive materials is reduced by the use of serial multistage HEPA filters.

8.1.1.12 Failure of Ventilation Blower (Category 3)

The plutonium process in the Deep Borehole Disposal Facility incorporates redundant ventilation systems as required to cope with the failure of a ventilation blower. Therefore, a temporary failure of a ventilation blower will not directly result in a release of radioactivity. This is judged to be an "anticipated" accident (as defined in DOE-STD-3009-94).

Mitigation features: The facility critical ventilation systems will be designed with redundant standby ventilation blowers.

8.1.1.13 Loss of Off-Site Electrical Power (Category 3)

The Deep Borehole Disposal Facility incorporates an emergency power source for safety-critical systems, such as the HEPA-filtered ventilation system and the emplacement crane equipment, as required to cope with a complete loss of off-site electrical power. Therefore, a loss of off-site electrical power will not directly result in a release of radioactivity. This is judged to be an "anticipated" accident (as defined in DOE-STD-3009-94).

Mitigation features: The facility will be designed with emergency diesel generators and an uninterruptible power system (UPS) for safety-critical system controls and operations.

8.1.1.14 Canister Dropped during Emplacement–Ruptured in the Emplacement Zone (Category 3)

A canister string could be dropped into the borehole as a result of a structural failure in the crane or the associated hoisting and securing equipment or as a result of operator error. A free-falling canister string could rupture on impact at the bottom of the borehole. Because of the large mass of Pu contained in a canister string, the high probability of its rupture if dropped, and the difficulty of its recovery, it is necessary to take precautions against such an occurrence. Because of side wall friction and fluid drag, unrestricted free fall of a released canister string is less likely to occur than a rapid descent into the borehole at a terminal velocity. The canister string may rupture if it impacts with sufficient velocity at the bottom of the borehole. If ruptured, the canister string will be sealed in place with grout, and the entire borehole will be sealed and abandoned with no further emplacement of fissile material in the borehole. If the canister is unruptured, it will be sealed in place with grout and emplacement operations may be continued to the full capacity of the borehole.

In view of the safety features in the design of the emplacing equipment and the administrative procedural controls that will be implemented, this type of accident is judged to be "extremely unlikely" (as defined in DOE-STD-3009-94). However, the severity of the accident and the associated risk is potentially significant because a ruptured canister string could release substantial quantities of the disposal form into the unsealed borehole. In the present accident scenario, only the environmental impact of the accident is considered without considering the possibility of a criticality accident that could possibly increase the threat to safety and the amount of fissile material released. The environmental impact of an accident without criticality is likely to be fairly localized onsite with minimal impacts to offsite areas.

The fissile material at risk in this accident scenario is the 1,012.5 kg of Pu contained in a canister string. It is postulated that one out of every twenty-five PCVs in the canister string, and the two product cans containing the Pu within each of the PCVs, will be ruptured, and that the Pu will be exposed to the air in the borehole. According to Walker (1981), 0.1% of the mass of Pu from the containers will become airborne and respirable. A containment building covers the borehole at the surface and is designed to contain the spread of fissile material in the event of an accident. It is assumed that all of the airborne material released in the accident will be transported by the circulating air flow from the borehole to the containment structure. Thus, the respirable fraction of the Pu released is 4.0×10^{-4}. The two-stage HEPA filters in the ventilation system of the containment building further reduces the fraction released by a factor of 10^{-6}. The final released fraction of the source material at risk is thus 4.0×10^{-10}.

Mitigation features: Administrative procedural controls and operator training programs will be established for extremely careful container handling to reduce the likelihood of this type of accident. Safety equipment such as single point fail-safe hoists, dead-man operator systems, clutch–brake interlocks, and periodic equipment testing will be incorporated in the design and operating procedures. Automatically opening brake fins/bladders that engage the borehole wall to slow and ultimately arrest the canister string during an accidental fall into the borehole will be incorporated in the canister string design. A containment structure with appropriate ventilation systems is included in the Emplacing–Borehole Sealing Facility design to limit the mass of airborne and respirable fractions of Pu released to the atmosphere.

8.1.1.15 Canister Dropped During Emplacement–Ruptured and Stuck in the Isolation Zone (Category 3)

This scenario is similar to the impact of a dropped canister string in the emplacement zone, except that in this case the canister impacts a projecting ledge at a change in the diameter of the well casings, ruptures, and remains stuck in the isolation zone rather than falling to the bottom of the borehole. This scenario is of greater concern than impact and rupture at the bottom of the borehole, because of the proximity of the isolation zone to the biosphere and the presence of more conductive transport pathways in the upper regions of the isolation zone. Thus it poses a greater threat to worker safety through fissile material transfer up the borehole and the larger potential for mobilization and transport of contaminants to the environment in the long term. The remedial action for this accident is to either dislodge the canister string from the isolation zone, or cut it into a few smaller sections if necessary, so that it falls into the emplacement zone. If ruptured, the canister string will be sealed in place with grout, and the entire borehole will be sealed and abandoned without further emplacement of fissile material in the borehole. If the canister is unruptured, it will be sealed in place with grout, and emplacement operations may be continued to the full capacity of the borehole. In view of the safety features in the design of the emplacing equipment, and the administrative procedural controls that will be implemented, this type of accident is judged to be "extremely unlikely" (as defined in DOE-STD-3009-94).

The total Pu contained in a canister string is 1,012.5 kg. This is the source term at risk in this accident scenario. It is postulated that, as a result of the canister being dropped, one out of every 25 PCVs in the canister string, and the two product cans within each of these primary containers, will be ruptured and will release the Pu in it to the moist air in the borehole. It is also assumed that sufficient moisture will be present in the moist air in the isolation zone and in water at the bottom of the emplacement zone to completely wet the exposed fissile material. According to the *Nuclear Fuel Cycle Facility Accident Analysis Handbook,* NUREG-1320, U.S. Nuclear Regulatory Commission, 6×10^{-6} of the Pu from the wetted material will become airborne and respirable. It is assumed that all of the airborne material released in the accident will be transported by the circulating air flow from the borehole to the containment structure. Thus, the respirable fraction of the material at risk is 2.4×10^{-7}. The two-stage HEPA filters in the ventilation system of the containment building further reduce the fraction released by a factor of 10^{-6}. The final released fraction of the source material at risk is thus 2.4×10^{-13}.

Mitigation features: Administrative procedural controls and operator training programs will be established for extremely careful container handling to reduce the likelihood of this type of accident. Safety equipment such as single-point fail-safe hoists, dead-man operator systems, clutch–brake interlocks, and periodic equipment testing will be incorporated in the design and operation protocols. Automatically opening brake fins/bladders that engage the borehole wall to slow and ultimately arrest the canister string during an accidental fall into the borehole will be incorporated in the canister string design. A containment structure with appropriate ventilation systems is included in the Emplacing–Borehole Sealing Facility design to limit the mass of airborne and respirable fractions of Pu released to the atmosphere.

8.1.1.16 Canister Stuck in the Isolation Zone (Category 3)

It is possible for a canister string to become stuck in the borehole during emplacement at a point other than its scheduled location in the emplacement zone. The most likely scenario involves the canister string getting stuck against the borehole wall because of contact with the wall on opposite sides of the borehole. This is more likely to occur where the borehole direction changes appreciably. On the other hand, in straight but tilted borehole sections, a canister will simply slide along one side of the borehole without becoming stuck. In the drilling industry, the curving of a borehole is measured in degrees of change in borehole direction per 30.5 m (100 ft) of borehole. The 10-m horizontal deviation in the KTB borehole at a depth of 4 km provides an indication of the amount of deviation that can be expected when drilling a deep borehole. At a depth of about 6 km, the drillers encountered a hard formation below a softer one that caused the drill bit to deviate from the direction of drilling in the softer formation. Consequently, the path of the borehole spiraled as it penetrated deeper into the hard formation.

If care is taken to drill the first part of the borehole straight, there would be very little deviation of the borehole thereafter. When drilling a straight hole, the load on the drill bit should be relatively low and the bit speed should be relatively high. These combine to give a straighter hole drilled at a relatively low penetration rate. However, if there are hard, sloping rock formations below softer rock formations, there is really not a great deal that can be done to prevent at least some deviation of the borehole. In the judgment of REECO and RSN drilling engineers, a 0.66-m-diam (26-in.) borehole can be cased without any difficulty with 0.51-m (20-in.) outer diameter casing run in 914 m (3,000-ft) sections. Since the 152-m (500-ft) canister strings are much shorter than the above casings, they anticipate no difficulty with canister strings becoming stuck in the borehole during emplacement.

After the borehole has been drilled, additional measures can be taken to further reduce the probability that a canister string will become stuck during emplacement. First, hole logs will provide excellent data concerning the shape of the borehole and will indicate regions that contain sharp changes in borehole trajectory. Second, a mandrel or dummy canister can be run into the hole to check for tight spots. This will provide a clear indication of any future problems with the real emplacements. Third, should data from the well logs or the mandrel runs indicate that the canisters may not pass through the borehole properly, an underreaming tool could be used to enlarge the hole. Fourth, the crane operator can closely monitor the load on the crane hook for signs that the canister is rubbing on the borehole wall and prevent uncontrolled descent of the canister. All of these precautions will be taken to reduce the probability of a canister string becoming stuck in the borehole to an extremely low value.

Given these measures, it is "extremely unlikely" that the canister string will become stuck in the isolation zone. If a canister were to become completely stuck in the isolation zone, however, it would have to be mined or drilled out to remove the material, or it could be cemented in place if it were deemed to be deep enough to achieve isolation. It is "beyond extremely unlikely" that a canister would rupture as a result of becoming stuck in the borehole. It is therefore assumed that no release of Pu would occur. The concern is that in the post-closure phase, the disposed material could more easily reach the biosphere. The severity of this is difficult to estimate, and further study is required. With a large void space below the canister string to be filled and sealed, there is an increased probability that small void spaces will remain below the canister string following cementing operations. They would not be expected to be large enough to have any impact on criticality.

8.1.1.17 Canister Stuck in the Emplacement Zone (Category 3)

It is possible for a canister string to become stuck in the emplacement zone of the borehole but above its intended depth. From the discussion in Section 8.1.1.16 on the factors that affect the lodging of canisters in the borehole, it is "extremely unlikely" that a canister would become stuck above its emplacement point. Extensive measures will be taken to ensure that a canister string does not become stuck in the first place. The probability of the canister becoming stuck in the borehole emplacement zone above its intended location is greater than the probability of becoming stuck in the isolation zone, because the casing provides added stability to the upper regions of the borehole. If a canister becomes completely stuck above the emplacement point, it could be cemented in place. It is "beyond extremely unlikely" that a canister would rupture as a result from becoming stuck in the borehole. It is therefore assumed that no release of Pu would occur. With a large void space below the canister string to be filled and sealed, there is an increased probability that void spaces will remain below the canister string following cementing operations. They would not be expected to be large enough to have any impact on criticality.

8.1.1.18 Emplacement Facility Electrical Fire (Category 3)

The extensive use of electric motors to drive the major mechanical systems of the emplacement facility makes it conceivable that an electrical fire might occur. These motors will be located much closer to the canisters [say 3 m (10 ft)] and the canister string than to the generators that power them. For this reason, a fire sprinkler system will be employed to quickly suppress any electrical fires. It is "extremely unlikely" that a fire associated with this equipment would occur. No release of Pu is expected because of the containment provided by the canisters.

8.1.1.19 Summary of Design Basis Accident Scenarios and Release Fractions

See Table 8.1.1.19-1 below.

8.1.2 Beyond Design Basis Accidents

As described in DOE-STD-3009-94, Section 3.4.3, the evaluation of accidents beyond the design basis is required by DOE Order 5480.23 for a facility Safety Analysis Report (SAR). The following paragraphs are excerpted here from DOE-STD-3009-94, Section 3.4.3, to define the scope of the beyond design accident analysis.

Table 8.1.1.19-1. Summary of Design Basis Accident Scenarios and Release Fractions.

Section	Accident Scenario	Accident Frequency(1)	Source Term at Risk	Respirable Fraction	Fraction Released
8.1.1.1	Earthquake	Extremely Unlikely	NA	No release	No release
8.1.1.2	Tornado	Extremely Unlikely	NA	No release	No release
8.1.1.3	Flood	Extremely Unlikely	NA	No release	No release
8.1.1.4	Pu storage container breakage during storage	Unlikely, 10^{-5}/container/yr	4.5 kg Pu	10^{-5}	10^{-13}
8.1.1.5	Pu storage container breakage during handling	Unlikely, 10^{-6} per handling	4.5 kg Pu	10^{-3}	10^{-11}
8.1.1.6	Emplacement canister dropped during handling	Unlikely, 10^{-6} per handling	40.5 kg Pu	No release	No release
8.1.1.7	On-site emplacement canister transportation accident	Unlikely, 1.6×10^{-6} per truck km	40.5 kg Pu	No release	No release
8.1.1.8	Criticality during emplacement canister filling	Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1.0 noble gas 0.25 halogen	1.0 noble gas 0.25 halogen
8.1.1.9	Criticality during Pu storage container spill	Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1.0 noble gas 0.25 halogen	1.0 noble gas 0.25 halogen
8.1.1.10	Fire in facility Process Areas	Extremely Unlikely	40.5 kg Pu	10^{-3}	10^{-9}
8.1.1.11	Failure of ventilation filter	Anticipated	NA	No release	No release
8.1.1.12	Failure of ventilation blower	Anticipated, 0.5/yr	NA	No release	No release
8.1.1.13	Loss of electrical power	Anticipated, 1/yr	NA	No release	No release
8.1.1.14	Canister string dropped during emplacement—ruptured in emplacement zone	Extremely Unlikely	1012.5 kg Pu	4.0×10^{-5}	4.0×10^{-13}
8.1.1.15	Canister string dropped during emplacement—ruptured and stuck in isolation zone	Extremely Unlikely	1012.5 kg Pu	2.4×10^{-7}	2.4×10^{-13}
8.1.1.16	Canister string stuck in emplacement zone	Extremely Unlikely	1012.5 kg Pu	No release	No release
8.1.1.17	Canister string stuck in isolation zone	Extremely Unlikely	1012.5 kg Pu	No release	No release
8.1.1.18	Emplacement Facility fire—electrical	Extremely Unlikely	1012.5 kg Pu	No release	No release

(1) Corresponds to terminology defined in DOE-STD-3009-94.

Descriptive Word	**Annual Frequency**
Anticipated	$10^{-1} \geq p > 10^{-2}$
Unlikely	$10^{-2} \geq p > 10^{-4}$
Extremely Unlikely	$10^{-4} \geq p > 10^{-6}$
Beyond Extremely Unlikely	$10^{-6} \geq p$

DOE Order 5480-23 requires the evaluation of accidents beyond the design basis to provide a perspective of the residual risk associated with the operation of the facility [see Attachment 1, paragraph 4.f(3)(d)11c, of the Order]. Such beyond DBAs are not required to provide assurance of public health and safety. Accordingly, they serve as bases for cost–benefit considerations if consequences exceeding the Evaluation Guidelines are identified in the beyond DBA range. However, such cost–benefit analysis would be performed outside the SAR with the concurrence of DOE.

It is expected that beyond DBAs will not be analyzed in the same detail as DBAs. The requirement is that an evaluation be performed that provides insight into the magnitude of the consequences of beyond DBAs (i.e., to provide perspective on potential facility vulnerabilities). This insight from the beyond DBA analysis serves to identify additional facility features that could prevent or reduce severe consequences from beyond DBA accidents. For nonreactor nuclear facilities, however, the sharp increase in consequences from DBA to beyond DBA is not anticipated to approach that found in commercial reactors, where the beyond DBA precedent was generated. No lower limit of frequency for examination is provided for beyond DBAs whose definition is frequency dependent. It is understood that as frequencies become very low, little or no meaningful insight is obtained.

Operational beyond DBAs are operational accidents with more severe conditions or equipment failures than are estimated for the corresponding DBA. For example, if a deterministic DBA assumed that releases were filtered because the accident phenomenology did not damage the filters, the same accident with loss of filtration is a beyond DBA. The same concept holds true for natural phenomena events (i.e., events with a frequency of occurrence that is less than DBA frequency of occurrence). Beyond DBAs are not evaluated for external events.

Based on the above clarification of the scope of the beyond DBA analysis, this group of accidents will be analyzed to a limited scale in the PEIS phase. The full-scope treatment of this group is beyond the scope of the Safety Analysis Report also. The information provided for these separate accident scenarios is summarized in Table 8.1.2.4-1 of Section 8.1.2.4.

8.1.2.1 Uncontrolled Chemical Reaction (Category 3)

There is no significant potential in the deep borehole disposition processes for uncontrolled chemical reactions that could lead to releases of radioactive materials. Hydrogen will be produced in the battery of the uninterruptible power supply system. It is believed that radioactive material release as a result of hydrogen accumulation in the battery room is unlikely. The occurrence of an uncontrolled chemical reaction leading to the release of radioactive materials is believed to be a “beyond extremely unlikely” accident as defined in DOE-STD-3009-94.

Mitigation features: Accumulation of hydrogen within the battery room would require that the UPS be isolated from the process ventilation system.

8.1.2.2 Criticality of Plutonium Container in Storage (Category 3)

The plutonium storage facility is designed to ensure that an accidental chain reaction is not credible. The facility is designed to preclude flooding in the storage area. Each storage can is limited to a quantity of Pu metal or PuO_2 that is adequately subcritical. The plutonium container storage array will maintain a subcritical safe geometry under both dry and flood conditions based on the use of concrete between storage slabs to reduce neutron interaction. Therefore, a nuclear criticality accident in the plutonium storage vault is judged to be a “beyond extremely unlikely” accident as defined in DOE-STD-3009-94. However, this is an area that will be further evaluated.

In accordance with Nuclear Regulatory Guide 3.35, the criticality events involve 10^{18} fissions in the initial pulse, followed by 47 additional pulses, for a total of 10^{19} fissions in 8 hr. In the criticality event described here, it is estimated that 100% of the noble gas fission products and 25% of the halogen (iodine) radionuclides would become airborne. This radioactivity would be released to the Zone 1 ventilation system. The exhaust HEPA filters do not mitigate the release of noble gases and halogens.

Mitigation features: The plutonium container storage array is designed to maintain a subcritical safe geometry and to preclude multiple batching.

8.1.2.3 Criticality of Emplacement Canister in Storage (Category 3)

The array in the emplacement canister storage area is criticality safe. The storage racks are designed to maintain the geometry of the array under all postulated accidents and natural conditions. The facility is designed to preclude flooding of this area. Therefore, a nuclear criticality accident in the emplacement canister storage area is judged to be a “beyond extremely unlikely” accident as defined in DOE-STD-3009-94.

Mitigation features: The canister storage racks are designed to maintain a safe geometry of the array under all postulated accidents and natural phenomena conditions.

8.1.2.4 Summary of Beyond Design Basis Accident Scenarios and Release Fractions

See Table 8.1.2.4-1 below.

8.2 Facility-Specific Accident Mitigating Features

Safety features will be designed to mitigate the consequences of the postulated accident scenarios. After each accident scenario, these features are identified and discussed, and their probability of failure and their impact on the Pu release frequency are estimated. These features are summarized here for ease of locating them as an aid to design.

The main mitigating features are of two classes:

1. Confinement/Containment Systems

2. Accident Progression Control Systems.

These features are in addition to the prevention and protection systems built into the design, construction, installation, fabrication, operation, and quality assurance of the structures, systems, and components (SSCs) by using industry-standard practices and methods. In addition, design margins (e.g., safety factors, increased tolerance, beyond design performance parameters) provide resistance to the occurrence of accidents.

The main mitigating feature of the confinement group is the ventilation system with HEPA filters. Redundant HEPA filters provide mitigation for release of Pu to the outside environment in the event of an accident that compromises the prevention and protection systems.

Table 8.1.2.4-1. Summary of Beyond Design Basis Accident Scenarios and Release Fractions.

Section	Accident Scenario	Accident Frequency(1)	Source Term at Risk	Respirable Fraction	Fraction Released
8.1.2.1	Uncontrolled Chemical Reaction	Beyond Extremely Unlikely	N/A	No Release	No Release
8.1.2.2	Pu Container Criticality in Storage	Beyond Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1 noble gas 0.25 halogen	1 noble gas 0.25 halogen
8.1.2.3	Emplacement Canister Criticality in Storage	Beyond Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1 noble gas 0.25 halogen	1 noble gas 0.25 halogen
8.1.2.4	Criticality of Canister Contents at Bottom of Emplacement Zone upon Rupture of Dropped Canister String	Beyond Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1 noble gas 0.25 halogen	1 noble gas 0.25 halogen

(1) Corresponds to terminology defined in DOE-STD-3009-94.

Descriptive Word	**Annual Frequency**
Anticipated	$10^{-1} \geq p > 10^{-2}$
Unlikely	$10^{-2} \geq p > 10^{-4}$
Extremely Unlikely	$10^{-4} \geq p > 10^{-6}$
Beyond Extremely Unlikely	$10^{-6} \geq p$

The main suppression feature is the automatic fire sprinkler systems and similar systems that assist operator actions for mitigation.

Seismically hardened design, tornado dampers, fire dampers, and construction of the facility grade above the maximum probable flood (MPF) level are examples of protection features that will be considered from the preliminary design stage through the construction stage.

Storage container design with low seal stress minimizes container breakage. Shipping packages and casks will be designed with double containment for transportation safety.

Redundant on-site emergency power system and UPS as a backup to the off-site power system is another important mitigation system against loss of off-site power. The battery room ventilation system mitigates the buildup of hydrogen gas in the room. Cranes, hoists, storage racks, and borehole steel lines are all designed for fail-safe operation.

Plutonium distribution is selected to ensure that an accidental chain reaction cannot happen to cause a criticality accident under water-saturated conditions. Placement of canisters, the amount of Pu metal or PuO_2 in the canisters, and the geometrical arrangement of the waste forms are designed to prevent criticality accidents.

9. TRANSPORTATION

9.1 Intrasite Transportation

9.1.1 On-Site Transportation of Radiological and Hazardous Materials

The transportation of radioactive material on-site at a DOE facility is not currently covered by Federal regulations. Regulations will be developed for the transportation of Pu, either weapons-grade material such as Pu metal or non–weapons-grade material such as PuO_2. The transportation of Pu in a weapons-grade form (metal) will be controlled by Defense Programs, and non–weapons-grade materials will be controlled by DOE-EH.

Proposed regulations that may govern the on-site transportation of radioactive materials are (1) Waste/Oxide–DOE 5480.X and (2) Weapons Grade Materials (Pits, Metal–DOE 5610.12). The on-site shipment of pits and weapons-grade Pu in metal form is currently not covered by regulation. Current practice varies from facility to facility. Regulations may be developed that utilize the graded approach to on-site packaging and transportation based on a yet-to-be specified hazard index (perhaps based on the type and quantity of radiation and on the criticality coefficient K_{eff}.) A strategy to develop a regulation for on-site shipment of weapons-grade Pu may include site-specific considerations.

The on-site movement of the Pu feed material and the Pu in its final disposal form does not represent a significant potential impact to the off-site environment, because the disposal form arrives on site in hermetically sealed primary containment vessels (PCVs), which are not opened on-site. The transportation routes used and the procedures adopted to mitigate any accident-related potential impacts are addressed below.

9.1.2 Feed Form Transportation to Surface Processing Facility

In this Deep Borehole Disposal Option, the feed material is in the form of Pu/PuO2 contained in PCVs, approximately 0.14 m (5.5 in.) in diameter × 0.51 m (20 in.) high, which are processed at an off-site facility. At a 5 t/yr Pu equivalent disposal rate, 1,111 transportation packages per year will arrive at the Surface Processing Facility. This feed material will be delivered to the Surface Processing Facility in DOE-approved inter-facility transportation trucks. No special safety or security requirements beyond those applied to off-site inter-facility transportation are required for on-site transit of these trucks from the site entrance to the Surface Processing Facility along the route identified as Plutonium Transportation Route 1 in the On-Site Transportation Map (Figure 2.1.2-2).

9.1.3 Disposal Form Transportation to Emplacing–Borehole Sealing Facility

Transportation canisters that arrive at the Surface Processing Facility are placed in larger emplacement canisters [6.1 m (20 ft) long] and sealed with sealants and mechanically threaded closure heads. These emplacement canisters are required to be transported by truck to the Emplacing–Borehole Sealing Facility along the route identified as Plutonium Transportation Route 2 in Figure 2.1.2-2. DOE-approved interfacility transportation trucks equipped with special canister-handling fixtures will be used. These enclosed trucks will conform to site environmental, Materials Control and Accountability (MC&A), and Safeguards and Security (S&S) standards.

9.2 Input Material Streams

9.2.1 Fissile Material Packaging for Transportation

Packaging Criteria

Shipments of radioactive materials fall into three categories: (1) low specific activity (LSA), (2) Type A quantities, and (3) Type B quantities. The Pu/PuO_2 product forms fall into the Type B category because of the amount of plutonium that must be transported in one package. A Type B package is designed to retain the integrity of containment and shielding when subjected to both normal and accident conditions. Because the total activity of Pu to be transported in the package is greater than the A_2 quantities for normal Pu forms, the material must be packaged in accordance with a DOT Certificate of Compliance, an NRC Certificate of Compliance, or a DOT specification package.

In addition, according to 10 CFR 71.63, Pu in excess of 20 curies per package must be packaged in a separate inner container placed within an outer container, with both containers meeting leak-testing requirements. This is referred to as the “secondary containment” or “double containment” requirement. Extra shielding for radiation protection is not required, because the radioactivity of the pellets is low. Finally, because of the large quantity of Pu per package, shipment by the Safe Secure Transporter System using a Safe Secure Trailer (SST) is required.

In addition to these standard requirements for licensing a transportation package, the direct disposal of Pu/PuO_2 at the Deep Borehole Disposal Facility requires that the disposal form be delivered to the facility in transportation containers in which all void spaces not occupied by the disposal form have been filled with an appropriate sealant. This is an essential requirement for ensuring criticality safety and satisfactory long-term performance of the deep borehole emplacement method. Because currently certified transportation packages do not allow the encapsulation of the Pu/PuO_2 with sealants that eliminate all void spaces, the packages would have to be appropriately tested and recertified for use under sealant-filled interior conditions.

Currently Available Packages

A preliminary search of available packages for the transportation of Pu metal/PuO_2 product forms indicates that a DOT 6M/2R-like specification package with a would be suitable for transporting 4.5 kg in two product cans, each containing 2.25 kg of material. However, as stated above, this package would have to be tested and recertified for use under sealant-filled interior conditions. Capacity and cost information for the DOT 6M/2R-like package is given in Table 9.2.1-1.

9.2.2 Transported Fissile Materials and Shipping Volumes

The input material streams that require transportation between the Deep Borehole Disposal Facility and off-site locations are listed in Table 9.2.2-1. The only radioactive input materials to the facility are the Pu/PuO_2 product forms originating at the Front End Facilities. The Pu/PuO_2 product is assumed to be transported in sealant-filled DOT 6M/2R-like packages. The maximum SST cargo weight of 5,443 kg (12,000 lb) permits a maximum of 40 of these packages to be transported in an SST per shipment.

Table 9.2.1-1. DOT 6M/2R-like Package for Transporting Pu/PuO_2.

Package Type	DOE 6M/2R-like
Plutonium/product can	2.25 kg
Number of product cans	2
Total Pu per 2R PCV	4.5 kg
Package + sealant weight	131.9 kg
Product + pkg + sealant	136.4 kg
2-month supply of packages	186
Total packages shipped	11,111
Cost per package	$2,000
Total purchase cost	$372,000

Table 9.2.2-1. Intersite Transportation Data.

Category	Input Material No. 1
Transported Materials	
Type	^{239}Pu
Physical form	Metal or oxide
Chemical composition	Pu or PuO_2
Packaging	
Type	DOT 6M/2R-like
Certified by	DOT/DOE
Identifier	NA
Container weight	131.9 kg
Material weight	4.5 kg
Isotopic content	93% ^{239}Pu, 6% ^{240}Pu 1% (trace isotopes)
Average Shipping Volume	
Quantity/yr	5 t Pu
Average number of packages shipped/yr	1,111
Total number of packages shipped	11,110 over 10 yr
Average number of packages per shipment	35 by SST
Number of shipments/yr	32
Total number of shipments	318 over 10 yr
Routing	
Destination facility type	NA

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11. GLOSSARY

11.1 Special Terminology

Bentonite: A naturally occurring highly impermeable and chemically sorptive clay material that contains the swelling clay material smectite. It can also contain quartz, mica, feldspar, and calcite.

Borehole Array area: The northern part of the Deep Borehole Disposal Facility occupied by the borehole array and including the Drilling and Emplacing–Borehole Sealing Facilities.

Casing: Structure used to line the borehole and to prevent an inflow of material or water.

Cementing: The process of pumping a grout slurry either into the borehole or into the space between the borehole wall and the casing in borehole cementing operations.

Closure period: The period extending from the ending of the operation period to the completion of backfilling and sealing the deep boreholes and decontaminating, decommissioning of the facility as a whole, and making the facility ready to be placed on post-closure status.

Concrete: A mixture of cement, sand, water, sand (“fine aggregate”) and 0.64- to 2.54-cm-diam (0.25–1.0 in.) solid particles called the “coarse aggregate.” Chemical additives such as water reducers and superplasticizers and swelling agents and materials such as silica fume and fly ash are often part of high-performance concrete formulations.

Construction period: The period extending from the beginning of construction activity to the commissioning of the Deep Borehole Disposal Facility for acceptance of Pu disposed form for disposal.

Disposal form: A generic term applied to the physical and chemical form in which the Pu material is emplaced in the borehole. In the present direct deep borehole disposed facility design it is Pu metal or PuO_2 backed in product cans contained in PCVs.

Disposal option: Any of a number of alternatives identified for permanently disposing of weapons-usable excess fissile materials.

Disposition option: Any of a number of alternatives identified for safely and securely storing, burning in reactors, or permanently disposing of weapons-usable excess fissile materials. These include long-term storage in combination with high-level nuclear waste in a mined geologic repository, use as fuel in special reactors to convert to nonfissile fission products, or geologic disposal in a deep borehole.

Drilling Facility: One or more drilling units each consisting of a drill rig, associated mud and water pumps, cementing trucks, storage tanks, standby generator, mud pits, personnel trailers, etc., as shown in the Drilling Facility Plot Plan.

Emplacing–Borehole Sealing Facility: One or more disposal form emplacing and borehole sealing units consisting of a crane, cementing trucks, pumps, waste treatment plant, personnel trailers, etc. as shown in the Emplacing Facility Plot Plan.

Emplacement canister: A metal canister in which a disposal form is emplaced within the borehole in canistered disposal options. Canisters are used in the direct disposal form option addressed in this report.

Emplacement zone: The bottom part of a deep borehole (2 km) where the disposal form is emplaced.

Grout: Specially formulated cement/sand/water mixtures with chemical additives. Differs from concrete by the absence of coarse aggregate material. Used for hydraulic sealing of void spaces.

High-level nuclear waste: Highly radioactive fission products resulting from reactor operations and nuclear fuel reprocessing that has radioactivity exceeding certain regulatory limits.

Isolation zone: The upper part of a deep borehole (2 km), extending from the top of the emplacement zone to the ground surface, used to seal and isolate the emplaced disposal form from the biosphere.

Main Facility: The southern part of the Deep Borehole Disposal Facility that includes all facility buildings and storage areas excluding the Borehole Array in the northern part. This includes the Surface Processing Facility, the Utility Support Facility, the Waste Management Facility, the Central Warehouse, the Administration offices, Security, ES&H and Medical Centers, the Fire Station and the personnel services building.

Mud: The fluid used in the drilling process. Often contains additives that cause it to appear mud-like.

Operation period: The period extending from the commissioning of the facility for acceptance of plutonium for disposal to the emplacement of the final load of plutonium and termination of accepting plutonium for disposal.

Post-closure period: An indefinitely long period (hundreds of millions of years) extending from closure of the facility to a time when the emplaced waste is no longer a security or safety hazard. It is expected that at least during the early years, the facility will be safeguarded and monitored.

Surface Processing Facility: The Pu processing area of the Deep Borehole Facility in the receiving and processing building in the Main Facility area.

Sealant: A generic term used to refer to materials used, to install low permeability seals within the borehole. The sealant materials for each of these uses are generally different and are as yet undefined although many candidate materials are being considered. The latter include grout, bentonite, bentonite/sand mixtures and other naturally occurring clays.

Transportation containers: Containers used for transporting Pu and PuO_2 from the originating facility to the Deep Borehole Disposal Facility.

11.2 Acronyms and Abbreviations

CFE	Critical Flood Elevation
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DBT	Design Basis Tornado
DOE	Department of Energy
DOT	Department of Transportation
EIS	Environmental Impact Statement
EKG	Electrocardiogram
EPA	Environmental Protection Agency
ES&H	Environmental, Safety, and Health
HEPA	High-Efficiency Particulate Air

HLW	High-Level Waste
HVAC	Heating, Ventilating, and Air Conditioning
IAEA	International Atomic Energy Agency
km	Kilometers
KTB	German Scientific Drilling Program
LA	Limited Area
LANL	Los Alamos National Laboratory
LLW	Low-Level Waste
LLNL	Lawrence Livermore National Laboratory
MAA	Material Access Area
MC&A	Materials Control & Accountability
MBA	Materials Balance Area
MPF	Maximum Probable Flood
MVA	Megavolt Amperes
MW	Megawatt, Mixed Waste
MWh	Megawatt Hours
NESHAP	National Emission Standards for Hazardous Air Pollutants
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
PA	Protected Area
PCV	Primary Containment Vessel
PEIS	Programmatic Environmental Impact Statement
PPA	Property Protection Area
PRA	Probabilistic Risk Assessment
psia	Pounds per Square Inch Absolute
RCRA	Resource Conservation And Recovery Act
ROD	Record of Decision

R&D	Research and Development
S&S	Safeguards and Security
SAR	Safety Analysis Report
SFM	Surplus Fissile Material
SFMCD	Surplus Fissile Materials Control and Disposition
SKB	Swedish Nuclear Fuel & Waste Management Co., Sweden
SNM	Special Nuclear Material
SSC	Structures, Systems, and Components
SST	Safe Secure Trailer
t	Metric Ton (1000 kg)
TRU	Transuranic Waste
UPS	Uninterruptible Power Supply
VA	Vulnerability Threat Assessment
WIPP	Waste Isolation Pilot Plant

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